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Color Demonstration Apparatus

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COLOR is a subject of considerable personal interest to most people having normal color vision, and possibly of even greater interest to the not too few known to have defective color perception.[1] A working knowledge of modern color theory is of professional value to students intending to specialize in the various arts, applied physics (the measurement and control of color is important in most industries), and in certain fields of science such as chemistry and biology.

Treatment of the subject in the presentation of elementary physics is generally meager; the developments in the field during the past two or three decades are neglected. For example, little space is ordinarily given to the important system for the measurement and description of color established in 1931 by the International Commission on Illumination. The ICI integrated the reliable psychophysical colorimetric data obtained by workers in this country and in England for observers having normal color vision, standardized the data (establishing a hypothetical "standard observer" and thus making it possible objectively to express color in numerical terms), and established a system for obtaining colorimetric quantities from such purely physical data as the spectral energy distribution of light. It is this system that makes it possible to refer to a spectrophotometer as a "color analyzer." A modern photoelectric recording spectrophotometer yields an accurate spectral reflectance or transmittance curve.

A spectral reflectance curve for a yellowish-green paper is shown in Fig. 1. Although such a curve is of important technical interest, it alone can impart only a qualitative notion about the color of an object as seen under ordinary illuminants. The ICI system enables one to obtain, for any given illuminant, the tristimulus values from the spectrophotometric curve and, from these values, the trichromatic coefficients. On plotting the latter on the ICI coordinate system (chromaticity diagram), one may obtain a numerical expression of the chromaticity of the color in terms of dominant wavelength and purity.

Since there is an abundant literature on the subject of color theory and measurement, selected writings are recommended for the reader desiring a comprehensive survey of the field.[2,3,4]

[1] Approximately one in 12 men and about one in 230 women have appreciably defective color vision. These persons are usually interested in the nature of their "color blindness" and, with the exception of the rare *monochromat*, enjoy limited forms of color perception; an acquaintance of the writer, a *dichromat* (requiring only two additive primaries to match all colors), tints photographs as a hobby!

[2] A. C. Hardy, *et al.*, *Handbook of colorimetry* (Technology Press, Cambridge, 1936); this book contains a number of tabulations of data and detailed charts of the ICI coordinate system, and is otherwise very useful.

[3] W. D. Wright, *The measurement of color* (Adam Hilger, Ltd., 1944).

[4] Report of the Committee on Colorimetry of the Optical Society of America, of which chapters 2, 5, 6, 7 and 8 have been published: *J. Opt. Soc. Am.* **33**, 544 (1943); **34**, 183 (1944); **34**, 245 (1944); **34**, 633 (1944); **35**, 1 (1945).

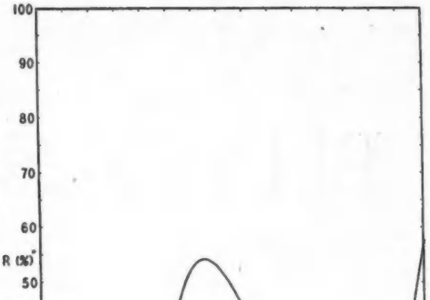

FIG. 1. Spectral reflectance curve for a yellowish-green cover paper.

In an elementary discussion of color, it is desirable to demonstrate the connection between color and spectral energy distribution of light (including, as a special case, the color of monochromatic light). The "color synthesizer" described in this article enables one to demonstrate any desired energy distribution and visually to show, in at least a qualitative manner, the significance of such quantities as dominant wavelength, purity, and luminosity. In addition, the apparatus may be used to demonstrate monochromatic and heterogeneous additive primaries, and to show the influence on color of a surrounding field of white light of variable luminosity.

Description of the Apparatus

The function of the equipment is to disperse the light from a tungsten-filament projection lamp into a spectrum, where the spectral energy distribution may be modified in any desired manner by means of a suitably shaped opening in an opaque sheet (hereafter referred to as the *modifier*), and then to combine the light in an integrating cavity in such a manner that the observer may perceive the mixed light. The principle of modifying spectral energy distribution by means of variously shaped apertures located in the plane of the spectrum was employed many years ago by Abney[5] and later by Ives and Brady.[6]

The apparatus, which may be assembled from ordinary laboratory equipment and may be constructed in various forms, is shown schematically in Fig. 2. Photographs showing the device as seen from the lecturer's position and as seen by the class are reproduced, respectively, in Figs. 3 and 4. The light source L is preferably a ribbon-filament projection lamp rated at 6.0 v and 108 w. A simple condensing lens L_1 forms a crude image of the lamp filament in the plane of lens L_2. Although the slit S should, ideally, be curved, good results are obtained with a simple, straight slit 2.5 to 3 mm wide and 40 mm long. Lens L_2 is placed at a distance from the slit equal to its focal length ($f=50$ cm is recommended) and is oriented with the prism P to produce a spectrum at M; it may be an inexpensive simple lens and may be slightly tilted about a horizontal axis if difficulty is encountered with stray light at M arising in surface reflections at L_2. A prism of the Littrow type (back surface silvered) was employed in order that the apparatus might be compact and readily portable; very good results may be obtained with an ordinary 60° prism,

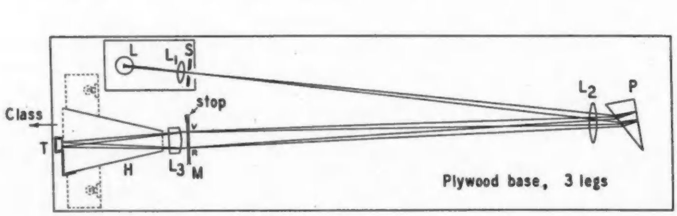

FIG. 2. Schematic plan view of the color synthesizer. The spectrum is formed in an area just above the slotted modifier support at M. The target T reflects nearly all the modified beam to the inner white surface of the cavity H, in which the light is mixed and from which the mixed light is emitted toward the observer.

[5] W. de W. Abney, *Colour measurement and mixture* (S. P. C. K., London, 1891).
[6] H. E. Ives, and E. J. Brady, *J. Franklin Inst.* **178**, 89(1914).

but equipment utilizing such a prism is awkward to carry and store because of its greater length and the "dog-leg" bend in the middle.

The adjustment of both the lens L_2 and the prism to form a spectrum at the relative position shown in Fig. 2 is facilitated by placing a "monochromatic filter" over the slit and mounting a white card at M for the purpose of viewing the approximately monochromatic image of the slit; if such a filter is not readily available, the lamp may be temporarily replaced with a mercury arc, and the adjustments performed with the green and yellow spectrum lines of mercury.[7] The modifier support M is located where the spectrum is formed; it consists simply of a narrow slot (formed, for example, by folding a 1×4-in. strip of thin brass sheet about its longer central axis), and it is mounted at such elevation that the top edges of the slot are just below the lower boundary of the spectrum.

After passing through the modifier at M, the beam is condensed by the lens L_3 on a small block of magnesium carbonate T, which diffusely reflects more than 95 percent of the incident light into the integrating cavity H. The focal length of L_3 is chosen so that this lens forms a crude image on the target T of the front face of the prism (for light incident on the prism—in other words, the object-to-lens distance is a few centimeters greater than the distance from L_3 to the back face of the prism). Lens L_3 is preferably a thick, inexpensive condensing lens of the kind used in lantern slide projectors; a lens of this description (selected for "whiteness" of glass) was used in the apparatus assembled by the writer, after a local optical company reduced its diameter to about 2.5 in.

The integrating cavity H, formed from fairly stiff sheet metal, has the shape of a truncated four-sided pyramid, although it is probable that other cavities, such as that which would be provided by a hemispherical shell, would function well. The dimensions of the cavity are not critical. The smaller opening should be just large enough to pass the visible beam, and the side dimension of the larger opening should be of the order of 70 percent of the distance between the openings. (It is of interest to note at this point that only about 2 percent of the light diffusely reflected from the target T escapes directly through the smaller opening.)

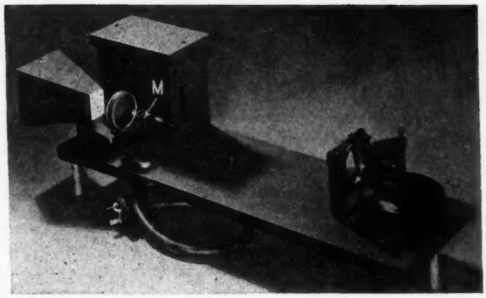

FIG. 3. Photograph of the color synthesizer, as seen from the lecturer's position.

It is important that the inner surface of the cavity be coated with magnesium oxide rather than white paint, because the reflectance of the latter varies appreciably with wavelength, and is apt to be too low for really effective results. It is a good plan, however, to use white paint as a base for the magnesium oxide. After the paint has dried thoroughly, the cavity is held over burning magnesium, with the large opening facing down, and moved around above the flame so that a fairly uniform deposit of the oxide is obtained. Magnesium ribbon (obtainable from scientific supply houses) is cut to roughly 7-in. lengths, and these lengths are burned one at a time until the thickness of the deposit in the cavity is of the order of 0.5 mm. It is suggested that the ribbon be held with pliers in an approximately horizontal position, and that the work be done under a hood. Goggles should be worn to protect the eyes. The coating of magnesium oxide is quite fragile, but will serve for a long period of time if not touched and if the instrument is stored in a clean place.

The source of any noticeable stray light can usually be located by moving a strip of cardboard around the optical system. One or more baffles of black paper can then be installed to eliminate the stray light. For example, a weak

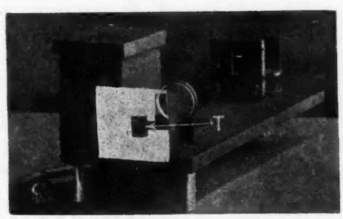

FIG. 4. Photograph of the color synthesizer, as seen from the observers' position.

[7] Strictly, the spectrum is formed in a slightly curved surface cutting across the beam at an angle. However, the functions of the apparatus do not require good resolution, and the support for the modifier at M (Fig. 2) may be arranged perpendicularly to the beam.

TABLE I. Filters for wavelength calibration.

Wavelength (mμ)	Filter
407	Wratten No. 38 (E. K. Co.)
441	Wratten No. 35
472	Wratten No. 30
538	Wratten No. 44
573	Wratten No. 59
626	"Aklo" heat filter* (Corning)
684	"Aklo" heat filter* (Corning)
700	"Aklo" heat filter* (Corning)

* Transmission 39 percent at 700 mμ; an "Aklo" filter having a somewhat lower value of T at 700 mμ would be more desirable.

secondary spectrum observed in making the first adjustments of the apparatus shown in Figs. 3 and 4 was traced to a real image of the lamp filament, formed in the lamp by reflection from the tubular bulb. The difficulty was eliminated by placing a narrow baffle over one limb of the lens L_2.

The lamp, lens L_1, and slit should be enclosed in a ventilated housing, which should be painted black inside and out, and otherwise designed to minimize the escape of light into the room.

The instrument is arranged on the lecture table so that the class can view the large opening of the integrating cavity. During the demonstration, the room should be as dark as possible because room light will lower the purity of colored light issuing from the cavity; this is of particular importance in the demonstration of monochromatic light.

Perhaps the first test of the instrument lies in the production, with a rectangular modifier in place, of light having the yellowish-white color characteristic of tungsten-filament lamps. With the exception of surface reflection losses, slight absorption in the glass optics, and a loss at the target of the order of 3 to 5 percent (depending on the quality of the magnesium carbonate), all the light from the slit passing through the lens L_2 should enter the integrating cavity.

Calibration

A number of interesting, although purely qualitative, demonstrations may be performed with the uncalibrated instrument. However, it is desirable to have reasonably accurate information on the relationship between wavelength and distance across the beam at M. The supporting slot at M for the modifier should be furnished with a stop at its far end. This stop furnishes a convenient fiducial point for the calibration.

Good results can, of course, be obtained by replacing the projection lamp with a mercury arc and other sources of line spectra. A white card placed in the modifier support at M is moved against the stop, and the positions of known spectrum lines are carefully marked on the card with a sharply pointed pencil.

Greater accuracy (in view of the wide slit) can be obtained through the technic of measuring effective wavelength.[8] The lens L_3 is temporarily replaced with a blocking-layer photocell, which is connected to a sensitive galvanometer. A rectangular piece of black paper (of about the stiffness of a playing card) is furnished with a slit about 2 mm wide and of length somewhat less than the vertical dimension of the spectrum formed at M. The back edge of this black card (the edge that touches the stop at the back of the modifier support when the card is moved away from the operator) is trimmed so that the distance between the edge and the center of the slit is definitely less than that between the violet end of the spectrum and the stop. A millimeter scale is mounted alongside the modifier support so that the position of the near edge of the black card (the edge toward the operator) can be noted. Then, knowing the distance from the back edge of the card to the slit, the reading on the scale when the card is in contact with the stop, and the scale reading for any position of the slit, one can readily obtain the distance between the slit and the stop.

With the black card set to pass monochromatic light of any desired wavelength, one then measures the transmission of a filter which is known to have a nearly linear spectral transmission curve of good slope in the region of that wavelength. The transmission is measured by noting the galvanometer deflections with, and without, the filter placed over the slit in the black card. The zero of the galvanometer should be obtained by placing a small opaque card over this slit. Care should be exercised to guard the photocell from stray light. The transmission of the filter having been measured, the effective wavelength is obtained from the spectral transmission curve of the filter. Or, if a recording spectrophotometer is available, the wavelength of the

[8] J. A. Van den Akker, *J. Opt. Soc. Am.* **33**, 257 (1943).

spectrophotometer is manually varied to yield a transmission for the filter equal to that observed with the color synthesizer.

If a spectrophotometer is not available in a nearby laboratory, it is suggested that the reader interested in this method of calibrating a color synthesizer make contact with one of the many educational and industrial laboratories employing recording spectrophotometers. These laboratories can readily furnish the complete spectral transmission curves of filters submitted to them.

Filters employed by the writer for calibration are listed in Table I. The wavelengths given in the table are near the centers of the linear portions of the spectral transmission curves of the respective filters; it should be permissible to employ wavelengths within a range of several millimicrons on either side of the values given.

The calibration curve is used in the preparation of the modifiers. After parallel lines are drawn on a black paper card to show the lower and upper limits of the spectrum, vertical lines should be drawn at the positions (obtained from the calibration curve) corresponding to 400, 420, 440, $\cdots$, 680, 700 mμ. Then, with the aid of a millimeter scale and a sharp pencil, the desired curve is laid out on the card and the opening is cut out with a linoleum knife or other sharp blade.

Demonstrations

Continuous spectrum.—If the class is not large, the students may be asked to come to the lecture table to observe the complete spectrum on a white card inserted in the modifier support or, if this is undesirable, the instrument may be rotated to show the spectrum to the seated group. The card may then be removed to demonstrate the elementary principle that a mixture of the continuum of monochromatic radiations from the source yields white light.

Monochromatic light.—A modifier consisting simply of a fairly wide slit (about 5 or 6 mm for good luminosity) is moved across the spectrum. It is suggested that white markers be placed on the black card so that the lecturer can call out the wavelengths, 400, 450, 500, $\cdots$ mμ as he slowly moves the slit through the spectrum.

Complementary colors.—Two rectangular openings, each somewhat wider than the spectrum, are cut in a black card, with a strip several millimeters wide separating the openings. This strip removes segments of the spectrum, thus presenting colors to the class that are complementary to those removed. Strikingly beautiful colors may be obtained through suitable adjustment of the width and position of the strip.

Additive primaries.—Three slits cut in a thin metal sheet, located to pass red, green, and blue-violet portions of the spectrum, and provided with vertically adjustable slides, enable the lecturer first to show the primaries alone, then in variable combination to yield an unlimited number of colors. With fairly narrow slits (a few millimeters wide), the use of monochromatic primaries may be shown. The use of heterogeneous primaries (covering a smaller range of possible colors) may be demonstrated by cutting wider slits in the metal sheet.

Color of various light sources.—In addition to the color of tungsten-filament light (rectangular modifier in position), of which ICI illuminant A is a standardized form, the lecturer can create light of relative spectral energy distribution closely similar to that of any one of several other light sources. The physicist often has occasion, in theoretical work, to employ the "*equal-energy spectrum;*" few physicists, however, have seen light of constant energy distribution. To prepare a modifier for the equal-energy spectrum, it is only necessary to plot ordinates on a black card proportional to $1/E$, where E is the spectral energy distribution of the light emitted by the projection lamp (this, of course, neglects selective losses in the instrument). For the purposes of demonstration, it is satisfactory to use E_A values (ICI illuminant A) for E.

ICI illuminant C, the reference source most commonly employed in this country for colorimetric work, may be demonstrated by preparing a modifier in which the ordinates of the opening are proportional to E_C/E_A where, again, E_A values are used for the energy distribution of the lamp. Values for E_A and E_C may conveniently be found in reference 2. Illuminant C is intended to simulate mean daylight, as exemplified by the light from a lightly overcast sky (mixture of sky light and sunlight). In a similar manner, if desired, an approximation of ICI illuminant B may be shown.

In discussing light sources, emphasis should be placed on the fact that the apparent whiteness of the light emitted by a source is a necessary but far from sufficient condition

that the source will be satisfactory for color matching. It is, of course, required of a light source for color matching that its light have relative spectral energy distribution closely similar to that of the light (for example, overcast daylight) which it is intended to simulate. The color synthesizer may be used to demonstrate the fallacy that whiteness of light alone is a criterion for effectiveness of the light in color matching. For example, a modifier may be constructed which passes only blue and yellow spectrum light in such relative amounts that white light is obtained. When held in this light, certain colored bodies assume a greatly different appearance from that seen under normal illuminants.

Color synthesis.—An accurate spectrophotometric curve giving, for example, the reflectance of a solid as a function wavelength is regarded by most physicists as the *sine qua non* of color analysis. When the ordinates of this curve are multiplied by the spectral energy distribution of the illuminant, the resulting curve gives the relative energy distribution of the reflected light (or transmitted light in the case of a transparent body), and the latter is fundamentally related to the color of the light that an observer perceives. When this product is multiplied by each of the three tristimulus functions of the ICI standard observer and these spectral products are integrated over all wavelengths, the resulting integrals become, when properly normalized, the tristimulus values of the color.[2]

The color synthesizer may be used to produce light of relative spectral energy distribution the same as that of light reflected from, or transmitted through, colored bodies and, hence, to reproduce the colors of bodies as seen under various illuminants. Let us consider the color of a body viewed in tungsten-filament light and, to be specific, consider the yellowish-green paper whose spectral reflectance is shown in Fig. 1. The spectral energy distribution of light entering the observer's eye after reflection from the paper is proportional to the product ER, where the two quantities are functions of wavelength. The spectral energy distribution of light produced by the color synthesizer is proportional, with fair accuracy, to the product Ey, where y is the ordinate of the opening in a modifier. Hence, if we prepare a modifier in which $y=kR$ (k being a suitable constant) and insert this modifier in the instrument, we will generate light of color similar to that seen when the paper is held under a tungsten-filament lamp.

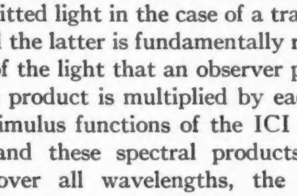

FIG. 5. Modifier for demonstrating the visual significance of dominant wavelength, purity, and luminosity. Luminosity is modified by varying the total energy of light entering the dispersing system. The dotted rectangle represents the limits of the visible spectrum.

This may be effectively demonstrated by holding a specimen of the colored paper alongside the integrating cavity (at a point just behind the front edge) and illuminating the specimen with a small tungsten-filament lamp. In doing this, the lamp must be placed behind the front edge so that its light will not enter the front window of the cavity and dilute the cavity light; this will necessitate holding the specimen at an angle with the plane of the window. It is suggested that the colored specimen and the lamp be held in the hands of the lecturer to facilitate the rapid demonstration of several colors. The distance between the lamp and the specimen should be manually adjusted to give a match between the luminosities of the light reflected from the specimen and of the light emitted by the cavity. Strikingly good results are obtained if the instrument is accurately calibrated and the modifiers carefully prepared.

This demonstration assumes greater educational value if the nature of the illuminant is changed. A "daylight" filter may be placed over the small auxiliary lamp, and the class may then compare the color of the specimen under simulated daylight with that of the same specimen illuminated with tungsten-filament light (the cavity light); on placing a similar daylight filter over the slit of the instrument, a near color match will again be obtained. As is well known, purples suffer the greatest change in color with change of illuminant and are, therefore, effective in this demonstration.

In order that the modifiers may be used a number of times, it is suggested that they be painted with thin cellulose lacquer. It is particularly important that the rear edge of a modifier be stiff and strong in the zone where it touches the stop located at the rear end of the groove support M (Fig. 2).

Dominant wavelength, purity, and luminosity.—The three attributes of color may be demon-

strated in an effective manner by means of modifiers constructed like that shown in Fig. 5. A horizontal opening of vertical dimension *a* passes a limited fraction of the whole spectrum in a nonselective manner; this light, after mixing in the cavity, should be "white" light of the same character as that emitted by the projection lamp. A vertical opening, of horizontal width *b* and height *c*, passes monochromatic light. The admixture of the white and monochromatic light simulates the mixture involved in the ICI monochromatic method of specifying color.[2] If the luminosities of the white and monochromatic beams are so adjusted that the color matches that of a sample, then the wavelength of the monochromatic light is the ***dominant wavelength*** for the sample (for the given white light source), and the luminosity of the monochromatic light relative to the total luminosity is the ***purity***. The total luminosity may be conveniently varied by moving wire-cloth screens of different transmissions into the beam near the opening in the lamp house.

The visual significance of dominant wavelength may be nicely demonstrated by simply sliding the modifier horizontally so that the vertical opening selects various wavelengths. While performing this demonstration, mention should be made of the fact that the purity of the various colors is not constant, because the luminosity of the monochromatic light varies from very small values at the ends of the spectrum to a maximum value near the middle of the spectrum while the luminosity of the white light remains constant. The visual significance of purity is demonstrated by varying the vertical dimension *a* of the horizontal opening. This may be simply effected by placing the lower edge of an opaque card lengthwise across the horizontal opening and varying *a* by vertical movement of the card (taking care to maintain the edge of the card parallel with the other horizontal boundary of the opening).

Effect of Surrounding Field of Illumination

The influence on color of surrounding colors and even of a surrounding neutral field of illumination is generally appreciated. For example, a colored object viewed in the typical environment of a room will give rise to a different response from that experienced when the same object, viewed under the same illuminant, is observed in a dark room—even when allowance is made for the fact that the walls and furniture of the room modify the character of the light falling upon the colored object. Let us consider the appearance of a piece of brown paper. On constructing a modifier for the brown paper and inserting the modifier in the color synthesizer, we are surprised to note that the cavity light is not brown, but straw-yellow or red-yellow, depending upon the nature of the original brown color. If now we surround the cavity with an illuminated diffusing screen, and gradually increase the level of illumination of the screen, we find that the cavity light (which has remained unchanged) appears to be brown. The effect of surround is striking in the case of the spectrum colors. The appearance of saturation of monochromatic light is often disappointing, because spectrum colors are usually viewed in a dark room, with a dark surround. The maximal saturation of spectrum colors can be appreciated when a surrounding field of white light of appropriate luminosity is provided.

Any means of providing an illuminated surround should be satisfactory if light from the auxiliary arrangement cannot enter the cavity and reduce the purity of the cavity light. This requires that the illuminated screen should be somewhat behind the front edge of the cavity, and that the lamps should be so disposed and shielded that light from them cannot enter the cavity, directly or indirectly. A fairly simple surround (position shown by dotted lines in Fig. 2) may be constructed of Masonite "Presdwood" in the form of a square, hollow frame, designed to fit around the shell of the cavity. The inside surfaces should be painted white; light may be provided by a number of flashlight lamps mounted on the back surface and connected in parallel. The front of the light box thus formed should be covered with panes of "flashed" glass or other neutral translucent material. The width of the illuminated frame thus formed need not be great; 2-in. panes of translucent glass should give satisfactory results.

It is a pleasure to acknowledge the suggestions and assistance given by Dr. Philip Nolan[9] during the development and construction of earlier forms of the color synthesizer.

[9] Now with the Farrand Optical Company, New York.

Diffraction by Two Non-Coplanar Obstacles

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IT has been observed that when sunlight passes between two obstacles which are not in the same plane perpendicular to the light path, a very interesting shadow is produced. When the distance between the two obstacles, measured along the perpendicular to the light path, is reduced so as to fall within a critical range of values, the shadow of the obstacle that is the more remote from the light source begins to bulge toward the shadow of the other obstacle. When this distance along the perpendicular to the light path is decreased still more, the bulging shadow finally merges with the shadow of the other obstacle, while the shadow of the latter obstacle has not bulged at all.

This phenomenon is illustrated in Fig. 1; the two obstacles are a straightedge and a circular disk, each beveled to a knife-edge, and the light source is the sun. In Fig. 1, *A*, are shown various stages of the bulging phenomenon corresponding to varying distances of separation perpendicular to the light path, with the straightedge in the more remote position from the sun; in *B* the disk is in the more remote position. In both cases the shadow of the more remote obstacle bulges toward the shadow of the nearer obstacle. In *C* the obstacles are coplanar and the shadows bulge toward each other. The distance between the obstacles in the non-coplanar cases was 10 cm, and the distance between the more remote obstacle and the observation screen was 40 cm.

To determine whether a true diffraction effect was implied in this phenomenon, diffraction patterns of coplanar and non-coplanar obstacles were obtained upon photographic film, use being made of a long path of monochromatic light under conditions of varying distances of separation of the obstacles both parallel and perpendicular to the light path.[1]

Description of the Apparatus

The light source (Fig. 2) used was a high-intensity mercury arc. A pinhole of diameter 0.5 mm was drilled in each of two brass shims 0.002 in. thick, and the shims were mounted in series in telescoping brass cylinders to provide for variable separation of the pinholes.

A Wratten green filter No. 62 was placed in the light path following the second pinhole to isolate the 5461A green mercury line.

A 2-m conventional optical bench was used to support the obstacles, which were mounted on two Gaertner traveling-microscope platforms. The distances *A* and *B* were kept constant throughout the measurements.

The obstacles were a straightedge and a disk, each beveled to a knife-edge. The beveled edges of the obstacles faced the film. The plane faces were blackened with India ink. A conventional film holder to accommodate a 4×5-in. film was supported so as to be adjustable horizontally and vertically. The film used was process contrast ortho, and each exposure time was 1 hr.

Procedure

Each obstacle was separately alined with the perpendicular cross-hair of a transit telescope, which had already been made to bisect the point source of light. The telescope was focused upon the edge of the obstacle, which was strongly illuminated and backed up by a piece of white cardboard. Each obstacle was separately moved toward the line joining light source and telescope, and readings of position were taken on the micrometer scale of the traveling microscopes. It was found that under good illumination the position of the edge of the obstacle could be determined to ±0.05 mm.

To obtain any specified transverse distance δ between the obstacles, the traveling microscopes' transverse platforms were backed away from the central position an equal distance as read on the scales of the traveling microscopes. This centered the light source with respect to the two obstacles. It is estimated that the error in the transverse distance between the obstacles did not exceed ±0.1 mm.

[1] Compare M. E. Hufford, *J. Opt. Soc. Am.* **27**, 408 (1937).

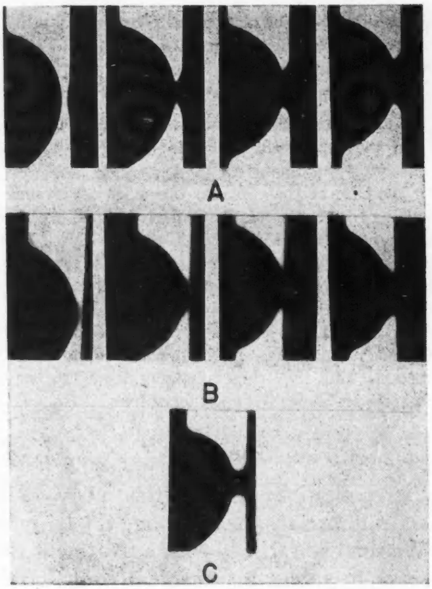

FIG. 1. Shadows of coplanar and non-coplanar obstacles observed in sunlight.

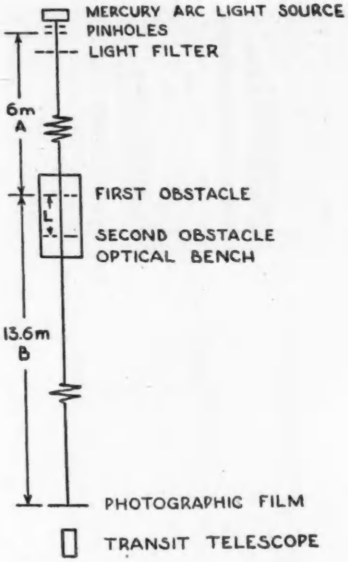

FIG. 2. Schematic arrangement of the light path.

The patterns shown in Fig. 1 are photographs of the shadows produced on a white cardboard by the straightedge and the disk. The optical bench was inclined so as to be parallel to the sun's rays. No attempt was made to determine accurately the transverse distance between the obstacles, since these photographs are intended merely to show in a qualitative way the bulging effect, which forms the starting point of this study.

Discussion of the Diffraction Patterns

In Fig. 3 are shown diffraction patterns[2] of the two obstacles, a straightedge and a disk, when the obstacles are in the same plane perpendicular to the light path. In the five patterns the distances between the edges of the obstacles are, respectively, 6.0, 6.2, 6.4, 6.6 and 7.0 mm for patterns *A*, *B*, *C*, *D* and *E*.

The diffraction patterns produced by the two obstacles can be described in the first approach as a superposition of the circular fringes due to the disk and the straight fringes due to the straightedge.[3] In those places where the two systems of fringes intersect, discontinuities are produced. The geometrical locus of these discontinuities produces the impression of a new system of fringes which form the boundary of lenticularly shaped areas. For easy reference this system of fringes will be designated "bulging fringes."

In Fig. 4 are shown two series of diffraction patterns with the obstacles non-coplanar and separated by a distance of 150 cm. In series *A* the disk is the more remote from the light source, and the transverse distance δ has the values 6.0, 6.2, 6.3, 6.4 and 6.6 mm, from *A* to *E*. In series *B* the straightedge is the more remote from the light source, and δ has the values 6.0, 6.2, 6.4, 6.6 and 6.8 mm.

As in Fig. 3, a system of bulging fringes appears, but those in the non-coplanar case do not bound lenticularly shaped areas. Instead, the system of fringes is characterized by a dissymmetry; the fringes that bulge from the more remote obstacle are clearly marked, and those from

[2] The pictures of diffraction patterns are photographs of the positives made by contact printing from the negatives containing the diffraction patterns.

[3] Photographs were obtained by superimposing the diffraction patterns of the two obstacles obtained separately. They resemble exactly the patterns of Fig. 3.

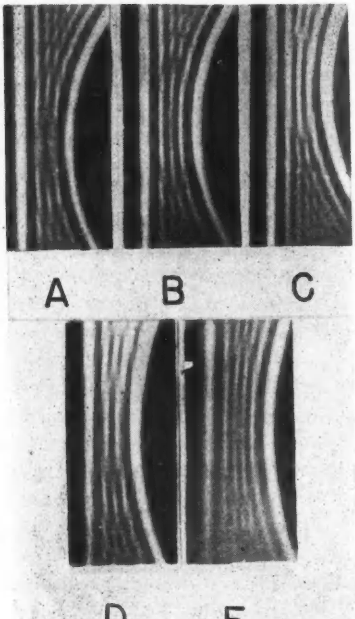

FIG. 3. Diffraction patterns of coplanar obstacles.

the nearer obstacle are missing almost completely. It is evident that we have here a diffraction phenomenon which has exactly the same dissymmetry as appears in the shadows photographed in Fig. 1. The inhomogeneity of the sunlight would make it impossible to observe the individual fringes in Fig. 1, and so it only appears that the shadow of the more remote obstacle from the sun bulges out and finally grows into the shadow of the nearer obstacle without the shadow of the latter obstacle bulging at all.

It can be seen in Figs. 3 and 4 that with increasing transverse distance of separation of the obstacles, the bulging fringes move toward the center of the patterns and disappear one by one. In Fig. 4, series B, diffraction pattern A has three distinct dark fringes (which are light fringes on the original negative) with a bulging fringe adjacent to the third fringe from the left. In B, where the distance δ has increased by 0.2 mm, the bulging fringe has moved more toward the center. In C, where the distance has increased another 0.2 mm, four fringes have made their appearance and the bulging fringe has moved to the left. A continuation of this progressive movement toward the center of the pattern can be observed. In series A the same general characteristics can be observed.

A great number of diffraction patterns were obtained—140 in all—in which the distance L (see Fig. 2) was varied from 10 to 200 cm and δ from 3.0 to 7.0 mm.

The following qualitative observations were made.

(*i*) The appearance of a system of bulging fringes arises from the superposition of the straight and circular fringes.

(*ii*) In the case of the coplanar obstacles the system of bulging fringes bounds lenticularly shaped areas that are symmetrical with respect to the center of the pattern.

(*iii*) In the non-coplanar case, a system of bulging fringes occurs, but the lenticularly shaped areas do not appear; instead, the center of the diffraction pattern appears to have been shifted toward the more remote obstacle and the fringes bulging from the nearer obstacle are almost completely absent.

Theory

No attempt at a rigorous treatment of the observed diffraction phenomenon will be made here. We shall be satisfied with a treatment that may serve to give a reasonable account of the dissymmetry noted in the foregoing description.

An approach to this problem may be made by calculating the shift in the "optical" and geometrical centers of the diffraction patterns in the

FIG. 4. Diffraction patterns of non-coplanar obstacles.

simplest similar arrangement, that is, Young's well-known experiment, modified in such a way that the two pinholes, illuminated by a point source, are not in the same plane at right angles to the line projected orthogonally from the light source to the screen.

Consider two pinholes O_1 and O_2 (Fig. 5) illuminated by a common point source of light of wavelength λ, originating at Q. Let O be the projection of Q on the screen S. The pinholes O_1 and O_2 are not in the same plane at right angles to QO. We are going to establish the condition that at a point x in the line S there is constructive interference.

Let a be the perpendicular distance between the light source and the first pinchole; b, the perpendicular distance between the first pinhole and the screen; δ, the transverse distance between the pinholes; and l, the distance between the pinholes along the light path. Then the two light paths L_1 and L_2 from Q to S are given by the equations:

$$L_1=(a^2+\tfrac{1}{4}\delta^2)^{\frac{1}{2}}+[b^2+(x-\tfrac{1}{2}\delta)^2]^{\frac{1}{2}},$$
$$L_2=[(a+l)^2+\tfrac{1}{4}\delta^2]^{\frac{1}{2}}+[(b-l)^2+(x+\tfrac{1}{2}\delta)^2]^{\frac{1}{2}}.$$

The difference between the two light paths terminating at x, when δ and x are treated as small quantities compared with a and b, is found to be

$$\Delta L=L_2-L_1\cong(a+l)\left[1+\frac{\delta^2}{8(a+l)^2}\right]+(b-l)\left[1+\frac{(x+\frac{1}{2}\delta)^2}{2(b-l)^2}\right]$$
$$-a\left(1+\frac{\delta^2}{8a^2}\right)-b\left[1+\frac{(x-\frac{1}{2}\delta)^2}{2b^2}\right].$$

Simplifying and setting $\Delta L=n\lambda$, we obtain,

$$x^2+\frac{\delta(2b-l)x}{l}-\frac{b(b-l)2n\lambda}{l}-\tfrac{1}{4}\delta^2\left[\frac{b(b-l)}{a(a+l)}-1\right]=0.$$

This quadratic equation for x has one root which goes to zero as l tends to zero, and one which goes to infinity as l goes to zero. It is the former root that we require, and it can be obtained with sufficient accuracy by treating x as a small quantity, that is, by neglecting x^2. The solution for x then becomes

$$x=\frac{b(b-l)n\lambda}{\delta(b-\frac{1}{2}l)}+\tfrac{1}{4}\delta l\left[\frac{b(b-l)}{a(a+l)}-1\right]\frac{1}{(2b-l)}.$$

For $l=0$ this reduces to the well-known expression for the position of maximum intensity in the Young experiment.

Thus, the result consists in (*i*) reducing the distance of the fringes (in the line S) from $\lambda b/\delta$ to $\lambda b(b-l)/\delta(b-\frac{1}{2}l)$, and (*ii*) shifting the "optical center" (to the right in the present case) by the amount

$$\Delta x=\tfrac{1}{4}\delta\left[\frac{b(b-l)}{a(a+l)}-1\right]\frac{l}{2b-l}. \quad (1)$$

By "optical center" we understand here that point on S which is characterized by the condition that $L_1=L_2$, that is, $n=0$. On the other hand, if we call the geometrical center the point that bisects the distance between the geometrical shadows, this geometrical center is shifted by a different amount. It is found by elementary calculations that the geometrical center shifts by an amount

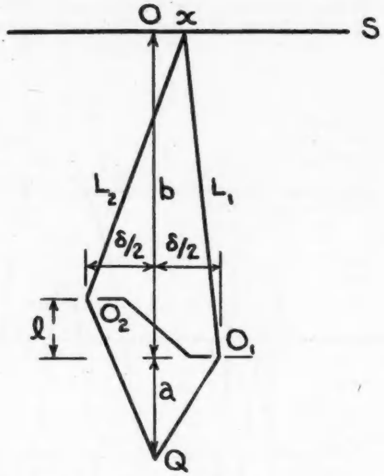

FIG. 5. Light paths used for theoretical treatment.

$$\Delta\xi=\frac{\delta}{4}\frac{(b+a)l}{a(a+l)}. \quad (2)$$

Therefore, the shift of the optical center relative to the geometrical center is

$$\Delta x-\Delta\xi=\tfrac{1}{4}\delta\left\{\left[\frac{b(b-l)}{a(a+l)}-1\right]\frac{l}{2b-l}-\frac{(b+a)l}{a(a+l)}\right\}. \quad (3)$$

It is seen from Eq. (3) that when a is very large the shift of the optical center is $-\frac{1}{4}\delta l/(2b-l)$, which depends upon l and b. Note that the shift is toward the pinhole that is the more distant from the light source.

The foregoing theory applies to a case that cannot be identified directly with our case of two non-coplanar obstacles. However, certain aspects of the calculation remain valid for this case. This is because in the rigorous theory of diffraction, the integral over the open area may be replaced by a line integral along the boundary.[4] This boundary, therefore, behaves like a luminous line which emits light that is coherent with the source. Hence the position of the fringes on the line S, as carried through above, remains valid.[5]

If, furthermore, we make the reasonable as-

[4] F. Kottler, *Ann. d. Physik* **70**, 405; **71**, 457 (1923).

[5] The position of the fringes for an ordinary slit is correctly given by the same method for the same reason.

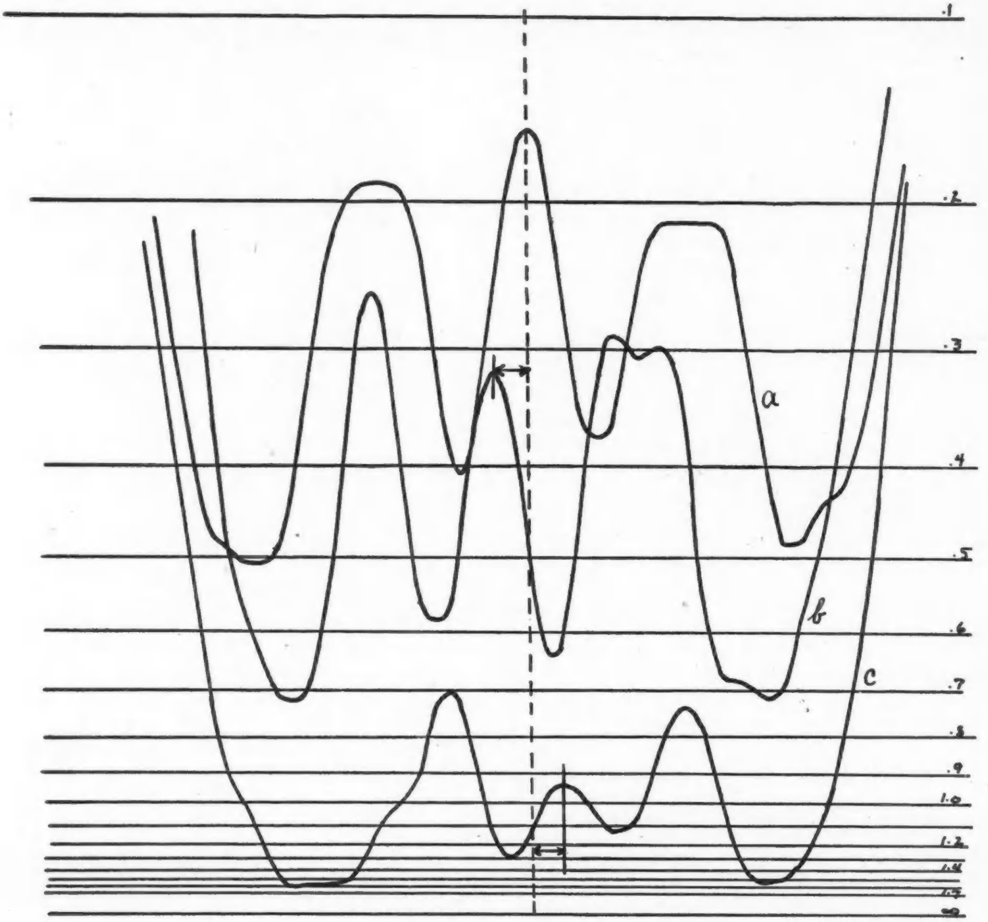

FIG. 6. Densitometer recording of diffraction patterns.

sumption that the optical center may be identified with the center of the lenticular areas, Eq. (3) yields the result that this center moves toward the second obstacle. Furthermore, it was qualitatively observed in the diffraction patterns that with increasing l the shift of the lenticularly shaped areas toward the more remote obstacle from the light source was more pronounced. From Eq. (3) it can be seen that the shift in the optical center with respect to the geometrical center is greater with increased l.

In order to compare the observed effects with our theory in a more quantitative way some densitometric measurements of the diffraction patterns taken on the photographic film were obtained. The diffraction patterns selected for this determination were a set of three, representing the coplanar case and the two non-coplanar cases where the disk and the straightedge, respectively, were in the more remote position from the light source.

In Fig. 6 are shown three densitometer tracings obtained through the geometrical center of the diffraction patterns on the original negatives. The chart readings represent directly the optical densities of the photographic film blackening.

The densitometer tracings of the diffraction patterns were made with a Leeds and Northrup densitometer and

recorded on a Micromax recorder. The tracing was made through a transverse section through the geometrical center of the diffraction pattern. The position of the transverse section through the center of the pattern was fixed by placing the film on a drawing board, determining the center of curvature of the circular outer fringe by means of a compass and then making a mark at both edges of the film on a line through the center of curvature perpendicular to the straight fringe.

Densitomer recording *a* of Fig. 6 is for coplanar obstacles; recording *b* is for the non-coplanar case, the disk being the more remote from the light source; and recording *c* is for the non-coplanar case, the straightedge being the more remote. The distance L of separation of the obstacles along the light path is 2 m in the two non-coplanar cases, and the transverse distance δ is 6 mm in all three cases.

The densitometer recordings have been traced from the chart and superimposed so that the lines through the geometrical centers perpendicular to the width of the patterns coincide. The geometrical centers have been determined as the points half-way between any two points of equal optical density along the outermost fringes.

The optical centers of the diffraction patterns are represented on the recording chart as the positions of the central fringe on the photographic film.

In tracing *b*, for which the disk is the more remote obstacle from the light source, it is to be noted that the optical center is shifted toward the left with respect to the geometrical center, that is, toward the more remote obstacle.

In tracing *c*, for which the straightedge is the more remote obstacle, the optical center is shifted to the right of the geometrical center, toward the more remote obstacle.

From Eq. (3) and the distances given, the shift of the optical center with respect to the geometrical center can be calculated to be 0.96 mm. As measured from the densitometer recordings, the shift is 0.70 cm in both cases of the non-coplanar obstacles, which is equivalent to a 0.67-mm shift on the photographic film; it is in the direction predicted by the theory. Better agreement can hardly be expected, given the preliminary nature of the theory.

Conclusion

The foregoing theoretical treatment explains the apparent bulging in the non-coplanar diffraction patterns as due to a shift of the "optical center" with respect to the geometrical center. This shift is in the direction towards the shadow of the more remote obstacle from the light source, so that only one side of the lenticularly shaped areas is visible, and the appearance is that of a bulging away from the more remote obstacle.

This work was done as partial fulfillment of the requirements for an M. S. degree at Louisiana State University. The author wishes to express his indebtedness to Dr. George Jaffé under whose direction the work was done.

The Sciences in General Education

The soundest element in the programs of general education now being adopted by liberal arts colleges is instruction in science—not in particular sciences, not in the metaphysics of scientific philosophy, but in the ordinary working assumptions of the scientific method; for example, controlled variables, verification, inference, and the like. This is certainly a step in advance of those beginning courses in chemistry, physics, biology or what not usually taught as if the beginner were going to become a professional research worker.

But a course in "general science," a course in the history of science, a course in the postulates of the scientific method will merely increase our technological confusion unless it is joined to something else. That something else is the study of what happens to scientific discoveries when they are practically put to work in our industrial culture. The woeful gap presently existing between the physical and natural scientists and the engineers on the one hand and the economists, sociologists, psychologists and anthropologists on the other hand is the most distressing fissure in our education as it is in our society. That as many persons as possible living in a technological culture should know as much as possible about the working assumptions of the scientists is patent—so patent, it is embarrassing that education has taken thus long to make this discovery of the obvious; but that the spread of this information, unless it is positively checked by other, sobering social forces may merely speed our descent into the maelstrom is also so patent as scarcely to require demonstration. Scientists, many of them, are genuinely distressed at the cultural lag between their work and the imperfections of the social processes which use the results of their labors. . . . The tremendous (and sometimes tragic) results of research for its own sake, when these results take the form of widespread technological change in modern society, are as basic to an understanding of the modern world as any part of scientific theory.—HOWARD MUMFORD JONES, *Education and world tragedy.*

Effect of Oscillations of the Case on the Rate of a Watch

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EIGHTY years ago Lord Kelvin[1] presented an interesting paper on the effect of the mode of suspension on the rate of a clock or chronometer. This paper reported on, and gave the correct mechanical interpretation of, the effects observed. The problem constitutes an interesting example of the theory of coupled oscillations, which readily lends itself to use in a junior course in mechanics as a laboratory experiment. For that reason it seemed to us that a modern presentation of the subject might be of interest.

It happens that many watches have the property that when hung up their period of oscillation as a pendulum is nearly in resonance with the frequency of oscillation of the balance wheel. In consequence a watch hung up in such a way as to be free to swing is set in forced oscillation as a pendulum. Sometimes on looking at a wall case full of watches in a watchmaker's shop most of the watches will be seen to be swinging away merrily on their hooks.

The rate of a watch that is swinging in this way is considerably changed, and therefore watches should not be so suspended when they are being kept in the shop for rate adjustment. We have made observations in the extreme case in which a well-regulated watch would gain or lose 10 or 15 min/day when its case was undergoing such forced oscillations.

We found, when a watch is hung up by its stem and free to swing as a pendulum, that not only is the rate greatly affected but also it varies considerably from day to day. This is probably due to accidental variations in the particular way in which the watch is hung on the nail. Table I gives data so obtained on a group of six watches. The first three lines give values of the rate in seconds per day[2] taken over 24-hr periods on three successive days when the watches were hung on nails and free to swing. The second three lines give the rates observed for the watches on the next three days when the watches were in the same position but clamped so they could not swing.

The problem is one of self-excited oscillations. The details will depend on the manner of action of the escapement, which is designed to excite torsional oscillations of the balance wheel with respect to the case.

In making an experimental study we found it convenient to make a small holder for the watch so that it could be suspended by a stiff wire as a torsion pendulum, with the plane of the watch horizontal. A threaded brass rod about 10 in. long was attached to the holder so as to be horizontal. This carried some brass nuts by which a fine tuning adjustment of the moment of inertia of the watch and support could be made.

First the length of the supporting wire was adjusted to produce resonance between the external oscillation of the case and the internal oscillation of the balance wheel when the nuts for fine adjustment were in the center of their range. Then a determination was made of the rate of the watch for each of a series of positions of the nuts. Later, with the watch not running, the period of free oscillation was determined for several positions of the nuts so that one had a calibration of the period of the torsion pendulum in its dependence on the position of the nuts.

In this way the data shown in Fig. 1 were obtained. Ordinates show the fractional change in rate of the watch; abscissas, the fractional departure of the oscillation frequency of the mount from equality with the undisturbed balance wheel frequency of the watch. It will be seen that the largest effect is obtained near resonance, as one would expect. Moreover, when the case frequency is below resonance the watch runs fast, and when it is above resonance the watch runs slow. The maximum effect was of the order of some minutes per day on a watch which when mounted rigidly was correct within a few sec-

[1] Kelvin, *Popular lectures and addresses* (Macmillan, 1894), vol. 2, p. 360.

[2] The sign + means that the watch is *losing;* − means that it is *gaining.* This sign convention arises from the definition of the *rate* of a time-piece as being the rate of change of the *correction,* where the *correction* is defined as the amount that must be added algebraically to the reading of the watch to give the correct time.

onds per day. This treatment seems not to produce any ill effects in the watch, which kept good time when rigidly mounted again at the conclusion of the experiments.

The theory of these effects is most conveniently considered first by studying the undamped oscillations of the free system. Let x be an angular coordinate measuring the departure of the case from its equilibrium position and let y similarly specify the orientation of the balance wheel with respect to fixed axes. Let I_0 be the moment of inertia of the balance wheel, and I that of the case and works and other parts of the torsion pendulum (with the balance wheel not turning relative to fixed axes). Likewise let k_0 be the torque per unit angle of the hair spring, and k that of the torsion wire by which the watch is supported.

The equations of motion of the free oscillations are then

$$I\ddot{x}+kx+k_0(x-y)=0,\quad I_0\ddot{y}+k_0(y-x)=0. \tag{1}$$

For convenience, write $\omega_0^2=k_0/I_0$ and $\omega_1^2=(k+k_0)/I$. Here ω_0 is the angular velocity corresponding to the proper vibrations of the balance wheel ($\omega_0/2\pi=2.5$ c/sec in most watches), and ω_1 is the angular velocity for the torsional oscillations of the case with the balance wheel not turning with respect to fixed axes. The

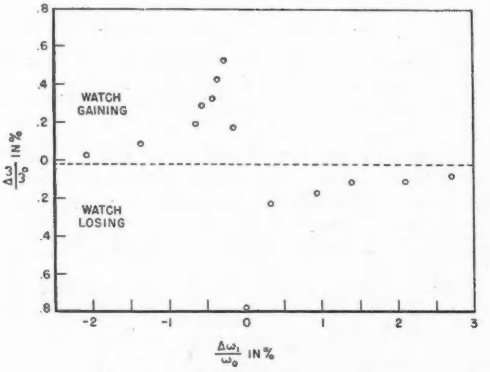

FIG. 1. Fractional change in rate of watch as a function of the fractional departure of the oscillation frequency of the mount from synchronism with the undisturbed balance wheel.

TABLE I. Rates (sec/day) of swinging and clamped watches.

Watch	A	B	C	D	E	F
Swinging	−403.4	−102.5	+668.5	− 99.2	−276.6	−329.0
	+948.9	− 93.5	+195.1	−111.9	−255.7	−160.8
	− 12.6	−196.7	+120.6	− 27.2	−245.3	−113.4
Clamped	− 2.9	− 3.5	− 45.0	+ 5.3	− 0.1	+ 1.0
	− 3.0	− 3.8	− 42.3	+ 6.1	− 2.4	+ 0.2
	− 2.0	− 4.4	− 47.5	+ 14.9	− 0.9	+ 0.5

equations of motion become

$$\ddot{x}+\omega_1^2x-\lambda\omega_0^2y=0,\quad \ddot{y}+\omega_0^2(y-x)=0, \tag{2}$$

where $\lambda\equiv I_0/I$. Assume $x=Ae^{i\omega t}$ and $y=Be^{i\omega t}$; then ω must have a value that determines the same value of A/B from each equation of motion:

$$A/B=1-\omega^2/\omega_0^2=\lambda\omega_0^2/(\omega_1^2-\omega^2). \tag{3}$$

In practice $\lambda\ll 1$. The interesting phenomena occur when the system is tuned so that ω_1 is nearly equal to ω_0. It is convenient to choose ω_0 as the unit of frequency. Solving Eq. (3) for ω^2 one finds

$$\omega^2=\tfrac{1}{2}(1+\omega_1^2)\pm\tfrac{1}{2}[(1-\omega_1^2)^2+4\lambda]^{\frac{1}{2}}. \tag{4}$$

In Fig. 2 the two roots are plotted as a function of ω_1 for two different values of λ, namely, $\lambda=10^{-4}$ and $\lambda=4\times10^{-4}$. At each value of ω_1 there are two roots, one corresponding to $\omega>1$, watch gaining, and one corresponding to $\omega<1$, watch losing. The first of these roots, from Eq.

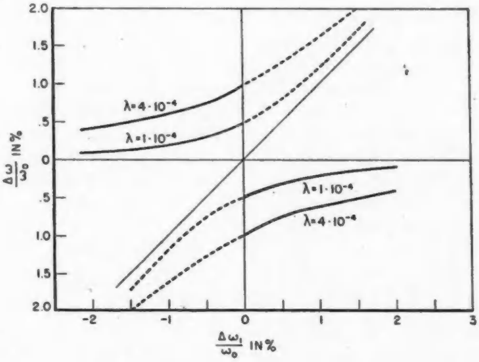

FIG. 2. Roots of Eq. (4). The solid lines correspond to observed values.

(3), corresponds to motion in which the case and balance wheel swing in opposite phase, while for $\omega<1$ they swing in the same phase.

But the experiments show behavior corresponding to only one of the two modes at each setting of the nuts. The mode actually observed to be excited in the experiments corresponds to the full parts of the curves in Fig. 2; the dotted parts were not realized in practice. Just why one of the modes is excited on one side of resonance, and the other is excited on the other side of resonance, is not dealt with in Kelvin's paper.

It seems quite likely that this depends on two factors, both of which favor the observed behavior. The mode excited is that one in which there is lesser amplitude of motion of the case compared to the balance wheel. Because of the large moment of inertia of the case relative to that of the balance wheel, the driving mechanism which exerts equal and opposite torques about the axes corresponding to the coordinates x and y, will be more effective in exciting such a mode. Likewise, the damping, hitherto neglected, due to air resistance, imperfect elasticity of the support and so on, will be mostly in the x coordinate. This has the effect of introducing a small term $+\alpha\dot{x}$ in the left-hand member of the first of Eqs. (2). The equation determining ω now becomes (with ω_0 as unit)

$$(\omega_1^2-\omega^2+i\alpha\omega)(1-\omega^2)=\lambda. \tag{5}$$

Since $\alpha\ll 1$, we may assume that the root will be of the form $\omega+i\alpha\theta$ to the first power in α, where ω is the root of the equation with $\alpha=0$. Substituting in Eq. (5), one finds

$$\theta=\tfrac{1}{2}(\omega^2-1)^2/[(\omega^2-1)^2+\lambda]. \tag{6}$$

This shows that the decrement of the motion ($e^{i\omega t}$ becomes $e^{i\omega t}.e^{-\alpha\theta t}$) becomes very small for that root in which ω^2 is close to unity. At each value of ω_1 one root is such that $(\omega^2-1)^2<\lambda$ and the other is such that $(\omega^2-1)^2>\lambda$. Hence there will always be a considerable difference in damping of the two modes, and the mode observed is the one of low damping.

The case in which there is no restoring force in the supporting wire was also commented on by Kelvin. From Eq. (3) with $\omega_1=0$ we see that $\omega^2-1=\lambda$, so that the watch always gains when suspended in this way. On the other hand, at resonance, when $\omega_1^2=1$, we see that $(\omega^2-1)=\lambda$, so that the effect there is greater in the ratio $\lambda^{\frac{1}{2}}$ than when there is no stiffness in the suspension.

It is a pleasure to acknowledge the cordial aid given by Mr. H. A. Bowman and Miss M. L. Scott of the Metrology Division of the Bureau in connection with the experiments.

It is remarkable how we delude ourselves that our mechanical advance is an advance of civilization. Nearly all that we rely on for our salvation at the moment is a series of elaborate devices for throwing things at one another. . . . Is it not a little humiliating to reflect that from the first stone thrown by an angry semi-ape at his brother to the latest battleship or bomber, men are settling their quarrels by a method which, morally, is now what it was then?. . . .

The scientists themselves are a little perturbed at the consequences of their restless prying, and it is right that they should be. Their defense is that their business is discovery, and that what use humanity makes of the thing discovered is humanity's affair: a defense I find as convincing as a Borgia's defense would be who said he had done nothing but put poison in the cup, and if his guest were fool enough to drink it that was his own lookout.—HOWARD SPRING, *And another thing* (1945).

The Need for Cooperation between Electrical Engineers and Physicists*

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THERE is a border field between physics and electrical engineering which does not lie wholly within either, and in which there is great activity at the present time. This area includes much of electronics, some of the work in nuclear energy, and much on radar, sonar and other equipment that was developed during the war. Certainly physicists have more interests in common with electrical engineers than with, say, mechanical engineers, or civil engineers, or chemical engineers. I believe the reasons lie partly in the historical development of electrical engineering and partly in the close relation of the content of electrical engineering to physics.

From the point of view of the development of basic ideas, physics prospered greatly when its experimental results attracted the interest of able mathematicians. Faraday's efforts were brought to full fruition only when examined in the light of the mathematical genius of Maxwell. The phenomena revealed in the experiments of Hertz were more effectively exploited with the aid of the mathematical reasoning of Heaviside. Tyndall's and Helmholtz's experimental results provided a basis for Rayleigh's theoretical expansion of the field of sound. This combined understanding of mathematics and physics, particularly when embodied in a single individual, has produced some of our greatest thinkers in natural science.

The electrical engineering departments with which I am most familiar either sprang directly from an already existing physics department or were established by an engineer who had a strong background in physics. Such an origin tends to give a more mathematical slant to the work of a department than one would expect to find in, say, a civil engineering department that was perhaps founded before physics came into its own. The mathematical slant, with its corresponding aptitude for analysis, has done much to foster the rapid development of a field whose basis lies in a "fluid" so dynamic as electricity. It is interesting to note that some of the recent advances in mechanical engineering have been made because of the freer application of mathematical concepts to mechanical things, and that many of the leaders of the present day in mechanical engineering are those who have been skilled in dynamic analysis. Even the civil engineers are now being required to give more consideration to dynamical concepts, and we may expect improvements in civil engineering design as these concepts are applied to the solution of certain types of civil engineering problems.

Because of the overlapping of their origins and the continuing parallelism of their points of view, it is only natural that the tie between physics and engineering should be closest in the electrical branch. This close tie has yielded much of benefit to both in the past, and it should continue to be fostered because of the advantages that may accrue in the future.

There is much work to be done by all who are interested in the important enterprise of improving the training of young engineers, specifically of those who wish to study electrical engineering. Nor do I see any prospect of a return to a pre-war level of effort in this over-all instruction problem. The increasing technology of this nation will, I believe, maintain a high level of demand for all varieties of engineering. If the problem of instruction of these engineers is to be met now and in the future, it will require the best cooperative efforts of teachers of physics and teachers of electrical engineering, not to mention the help that will be needed from teachers of mathematics, economics, language and literature.

I believe it is particularly important that students of electrical engineering learn their basic physics from men who are professional physicists. This may not result in the instruction in physics being carried on exactly as the electrical engineers would do it if left to themselves, but I believe that there is more gain than loss in having it done this way. The physicist must, of necessity, take a broader view of the world around him than the electrical engineer. His training covers not only electricity, but also heat, light, sound, and

* Presented at the Minneapolis Meeting of the American Association of Physics Teachers and the American Society for Engineering Education, June 1947.

atomic and nuclear physics. It is desirable that young men be introduced to physical science by persons who are familiar with and accustomed to thinking in all these fields. Furthermore, it is the physicist's business to be acquainted with the latest developments in all these fields; and, if he does his job well, he will impart to his students some modicum of interest in this broad view.

On the other hand, the importance of the views of the electrical engineer in these matters should not be underestimated. The engineer's job is the application of natural phenomena and principles to the improvement of the lot of mankind. If he is to do this successfully, it is essential that he focus his efforts on phenomena that have a reasonable possibility for rather immediate application, and he cannot, therefore, devote too large a share of his training to the study of phenomena whose application is remote even in a long-range view.

The professions of physics and engineering, particularly electrical, are both suffering from disruptive forces tending to break them down into smaller and smaller units. The disintegrating force present in physics has shown itself by the establishment within the American Physical Society of smaller and more specialized units. A strong effort has been underway for nearly 20 years to counter this disintegration, leading to the establishment of the American Institute of Physics as a rallying point around which all physicists can gather. Disintegration in the engineering profession has gone much further. We now have nearly 100 different engineering societies in this country and no common rallying point where a common effort can be asserted or interest defended. There have been frequent efforts to reverse this trend, one of which is in progress at the present time.

There are other professions which seem to have resisted this tendency to disintegration somewhat more successfully than engineering. Why is it that the medical profession, for instance, seems to be much more closely knit than the engineering profession? There is, I believe, one important reason for this to which I would like to call attention.

When my great-grandfather studied medicine, the medical school which he attended was a very informal affair. The formal education required for entrance was a very low minimum, and the standards required for graduation, set by a small local group, were also very low. In contrast to this we now find that medical training requires four years of college, four years of medical school, and a two-year apprenticeship, all in institutions closely supervised by the medical profession. Training of this kind and extent leads to close and rigid selection, so that only the most able complete it successfully, and it tends to inculcate a unity of purpose and a commonness of point of view that cement those who undergo it into a closely knit profession. We may contrast this with engineering training, which now indeed requires four years of college work in institutions supervised and approved by the profession. To this is added a considerable, but not very clearly defined, recognition that a few years of practical training, usually supplied by industry to meet immediate needs, is necessary before the engineer can make any very substantial contributions.

In engineering we have been trying to pack more and more instruction into the four college years, until the curriculum has now really burst its seams, and several institutions are going over to five-year courses. Is it possible that in the not-too-distant future we may find it desirable, or even necessary, to recognize that if engineering is to do its job on a high plane in this world of increasing technical complexity, its training may have to approach in thoroughness that of the medical profession?

We recognize that the best type of engineer needs a substantial indoctrination in the liberal arts. He frequently needs greater facility in mathematics than his training now supplies. He could often profit by a broader and deeper understanding of physical phenomena than his four-year course permits. If these needs could be supplied, his specialization could be more rapid, more inclusive, and more assuring.

It has become generally accepted that physicists, if they are to enter first-line competition, require seven years of formal training, and the most fortunate follow this with two years of apprenticeship under a fellowship grant. This more extensive training and tougher standard, in my opinion, puts the physicists ahead of the engineers in clarity of professional recognition. This clarity will make it easier for them to resist

disintegration of their profession. I believe that, if and when engineers deem it worth while to require a training of similar extent and scope, it will result in increased unity of the profession, and yield an integration which may prove difficult to achieve otherwise.

My experience in the war years throws some light on the effect of broad training on the progress of an individual and, in particular, on the advantages of training in both physics and engineering. The Naval Ordnance Laboratory, with which I have been associated during these years, employs approximately 1800 people, of whom between 700 and 800 are professionals. This organization grew from a start in 1940 of about 50 people, of whom about a dozen were professional. The organization comprises three technical departments (in addition to several service departments) under the headings of Research, Engineering, and Technical Evaluation.

The heads of each department entered and came up through the organization during the war years. The chief of our Research Department is a physicist who has, however, a distinct appreciation of engineering and has done much work in that field during the war. The chief of our Engineering Department was trained initially as an electrical engineer, but took his advanced degree in physics. He has a breadth of view that is most useful in dealing with the wide range of problems which we encounter, not only in engineering, but in our research efforts also. The chief of our Technical Evaluation Department was trained as a civil engineer, but first rose to prominence in the laboratory through his skilful studies in hydrodynamics.

We have found that in order to develop weapons successfully we must underestimate neither the importance of physicists nor that of engineers. There were a number of developments carried out during the war by organizations composed almost entirely of physicists. These groups made some remarkable achievements, but the Naval Ordnance Laboratory has inherited the problem of engineering a number of their products to the end that they may prove durable and reliable in service and that they may be bought with reasonable economy.

On the other hand, we have examples of attempts to develop weapons without the advice and consultation of persons skilled in physics. They have resulted in weapons that operated satisfactorily in the North Atlantic, but were of no use in the South Pacific; weapons that seemed to perform adequately under test, but failed under combat conditions. An important factor in the failure of these devices was a lack of understanding of all the phenomena involved on the part of engineers who developed them.

I do not feel that the Naval Ordnance Laboratory could possibly accomplish its mission either without physicists or without engineers. The experience of the Navy, particularly in previous peacetime years, has shown that weapons developed by engineers alone may be insufficiently imaginative to meet the challenge which the future will offer. Its experience in wartime development has shown that weapons developed by physicists alone may lack the qualities necessary to assure performance in the face of rugged combat conditions. I am convinced that research and development can be carried out successfully only by an organization that combines an adequate number of persons of both professions and that it will prosper in proportion to the appreciation of each profession for the virtues, qualities and abilities of the other. I, therefore, hope that we may look forward to continued cooperation between members of both professions, for discussion of their mutual problems and appreciation of each other's points of view, and that the spirit engendered in such association may be passed on to the young men whose training is entrusted to their hands. We must never forget that the future of this nation, both in its peacetime economy and in its wartime strength, depends very largely on the success of their efforts in the training of young men in science and technology.

Whenever you look at a piece of work and you think the fellow was crazy, then you want to pay some attention to that. One of you is likely to be, and you had better find out which one it is. It makes an awful lot of difference.—CHARLES F. KETTERING.

Physics Examinations and the New Curriculum

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I

Reform in teaching and education is often hindered, as a noted English educationist somewhat pointedly said a few years ago, because teachers who are successful in "the old way" don't want to change their methods, and those who are willing to try a new approach lack the experience on which the success of any method depends. Different as their reactions are, both groups would presumably be reassured, and their receptiveness to new methods, as well as competence in administering them, increased, by access to tested examinations applicable to the modified types of instruction.

In particular, teachers accustomed to conventional classroom treatment of physics, primarily shaped by the professional needs of engineers and physicists, are inclined to be unnecessarily shy about approaching the subject in a broader setting which could make it of real value to nonspecialists and specialists alike. Even physics teachers themselves, in their more candid moments, admit that the results of their efforts leave much to be desired. But too many of them place the blame on the student or his preparation, and too few examine the narrow point of view in their own classroom procedure.

The mathematical approach and the extended use of numerical examples have their proper, prominent place in the teaching of even elementary physics. But as this paper will try to show, some of the basic objectives of examinations ordinarily involving mathematical and numerical examples can be attained in other ways, thus avoiding some of the unfortunate negative reactions attending too exclusive a reliance on mathematical rigor, and allowing the introduction of those educational or cultural aims forming the fundamental feature of the new physics curriculum.

Psychology has taught us that our thinking is intentional, directed towards or onto something. The learning process in particular is a purposive process. Hence, if we set our students examinations of the problem type and consider them expressly as the best means of testing a student's ability, the students will—by hook or by crook—try to "do" their problems. Whatever else the lecturer may attempt to present to his class will largely miss the point. Wherever examinations are set by external examination boards, these conditions will become very acute, and the lecturer may very well be called to order if he teaches something outside the usual, the students themselves demanding "service" instead of education. And we cannot blame the students; their attitude is fixed through economic pressures, and their attitude to learning is given by the examination requirements, not by any additional cultural aspects the lecturer wishes to introduce.

Modern educational reformers, for the reasons mentioned, are of the opinion that an improvement in our teaching is possible only by abolishing examinations. As far as schools go, the ideas have been more or less accepted that we must never apply the procedure of selection but that of differentiation, and that examinations should be used as a means of the latter and not of the former. In colleges and universities some selection certainly is necessary, and the earlier a reliable selection takes place, the better for the student and the educational institution. Physics examination results could be a true means for guidance and selection if we expand our curriculum and change the examinations accordingly.

If, instead of testing merely some knowledge of facts and some routine reasoning processes, we could find out whether a student can follow a train of ideas, appreciates an historical situation in science, expresses himself in an intelligent way, is able to "read a formula," to "read a graphical representation," understands a passage of scientific exposition—then the physics examination would be a real test of the student's intellectual achievements. The examination paper must be so constructed that the student is induced, or we may even say compelled, during his studies to pay attention to the whole realm of ideas brought forward by the instructor. The intentions of the lecturer will then become the

intentions of the students. Occasional tests before the examination will accentuate the sphere of knowledge the instructor wants specially to impart to his class, which will be in the new curriculum an integrated study, a thinking in terms of functional connections and cultural implications. I am fully aware that this formulation of our aims may be open to challenge. We will find much misunderstanding, but our instruction will be, by our modern standards, more valuable in all those cases where the correct understanding has been reached. Discriminating examiners will remember that students should not be judged by the occasional "blind spot" disclosed in even the best of them by any single examination. Every professional man will admit to certain *lacunae* in his own field.

II

Physics instructors in agreement with the modern trend toward a cultural physics curriculum may still be in doubt about how to test the applicable knowledge and reasoning power of their students without the proven instrument of numerical problems. Attempts have been made to use the objective tests of the reasoning type,[1] and they certainly can be very usefully applied to replace problems and to probe deeper into the student's understanding. But objective examinations can be used successfully for an even wider purpose. Problem examinations have the great advantage that they can be easily set from published examples with minor modifications to avoid repetition. In contrast, construction of an objective test is laborious, but it pays not only through the much better evaluation of student achievement, but also by helping the instructor to a better understanding and formulation of his own ideas.

Methods of objective testing of this kind seem not to have been widely applied in physics instruction on the college level. A few examples of such objective tests follow. It is to be expected that other physics teachers may have made similar experiments, and that by assembling the existing material a way can be found to convince physics instructors who are inclined to try the cultural approach that there need be no superficiality connected with it, and that effective means of evaluating student achievement in this field are available.

The testing of memory unavoidably plays a large part in any examination. Perhaps we do not need to apologize unduly for that fact. Though we must not overload our students with detail, modern life depends to a great extent on certain details of knowledge, from traffic rules to first aid. To include some questions involving memorization is not necessarily a concession to weak students. The best way to test such knowledge is by completion tests or matching tests. Both kinds of test can be used for testing understanding, and are applicable not only to verbal expressions—that is, to vocabulary testing—but to mathematical expressions. These tests belong to the reasoning type when they are well formulated.

A question that requires knowledge of facts and understanding of principles is the following:

Under the influence of a uniform electric field, ions in solution travel with constant velocity because
(*a*) there is no force acting upon them (.....)
(*b*) there is a constant force acting upon them (.....)
(*c*) there is no friction (.....)
(*d*) there is friction (.....)
(Two answers are compatible; check with X.)

The application of this type of test to the evaluation of mathematical understanding may take the following line:

Let h_1, p_1 and v_1 be, respectively, the elevation, pressure and velocity at a certain point in a liquid having a mass d per unit volume, and let the liquid by flowing arrive at a point where the respective quantities are h_2, p_2, and v_2; then

$$gh_1+(p_1/d)+\tfrac{1}{2}v_1^2= \ldots\ldots$$

Who stated this law? ......
What general principle is involved in this equation? ......

Combined with a verbal test the answer to the whole question shows the degree of knowledge and understanding. Many students remember the name Bernoulli (with a great variation in spelling) who cannot complete the equation, and only a few are able to complete the last part.

A much simpler case is the full statement of a familiar formula:

$$R_t=R_0(1+\alpha t),\ \text{where}\ R_t= \ldots\ldots$$
$$R_0= \ldots\ldots$$
$$\alpha= \ldots\ldots$$
$$t= \ldots\ldots$$

(Complete.)

[1] A. G. Worthing, "The usefulness of objective physics tests of the reasoning type," *Am. J. Physics* (*Am. Physics T.*) 1, 6 (1933).

The letter t will sometimes even be mistaken for time. Such interpretive questions can be very revealing.

A question requiring knowledge of laws which are not explicitly stated, understanding, and some power of reasoning is the following:

A lamp A has a temperature of 3250°C, and another lamp B has a temperature of 2740°C. Considering both Stefan's and Wien's laws of radiation, which lamp will emit:

more ultraviolet rays? A (.....) or B (.....)?
because of .....'s law;

more infra-red and visible rays? A (.....) or B (.....)?
because of .....'s law.

(Check with cross and complete.)

Completion tests are useful also for probing the understanding of nuclear reactions, for example:

Complete these equations:

$$(a)\quad {}_{13}Al^{27} + {}_{2}He^{4} = \ldots P^{\cdots} + {}_{0}n^{1}$$
$$\downarrow$$
$$\ldots Si^{\cdots} + e^{+}$$
$$(b)\quad {}_{3}Li^{7} + {}_{1}H^{1} = 2 \ldots He^{\cdots}.$$

In these and other instances it is necessary, if understanding rather than memory is to be tested, not to use the same reaction, or the same way of writing a formula—as in Bernoulli's principle—as has been stated in class.

The multiple-choice test, as applies frequently, has one pedagogic disadvantage. The student who gives the wrong answer but believes he has given the correct one, in this way memorizes an incorrect statement. It is not always certain that the subsequent discussion of a test is appreciated.

The completion of graphs, that is, labeling and explaining them, and of simple drawings of apparatus and instruments is also practicable. To give in a figure the graph for, say, the Duane-Hunt law or the van der Waals equation, and to ask the student to label the graph and state in a few words its importance, gives satisfactory results. A graphical completion does not draw unduly on the often poor draftsmanship of the student. When the costs of printing must be considered, the number of graphical completion tests can be reduced, and free space left on the examination paper for students' drawings.

Because of the difficulty students have in expressing themselves clearly enough, essay writing in an examination is a very doubtful means of testing. Very often the student will tell what he knows in some connection with the question asked, but will skip the real question. Often the account is verbose, and the examiner finds it difficult to separate the correct from the incorrect answer, or he has to guess the intentions of the student's statements. A better way in essay writing is to give the student, along with the topic, a number of words or phrases—key words—which he has to use in the given order; for example:

Write a short paragraph (about 100 words) on the kinetic theory, making use of the following expressions in the given order: ideal gas, Boyle's law, mechanical momentum of the molecules, gas pressure, kinetic energy of molecules, absolute temperature, Avogadro number.

This kind of test is not fully objective, but allows a very fair evaluation of a student's knowledge and understanding, as well as of his ability to express himself in a well-arranged manner on a definite topic.

A somewhat more objective way of testing discrimination in the use of terms is the following type of "guided calculation:"

The velocity of a gas molecule is v, and its mass is m; therefore its momentum is ...... An elastic impact with the wall changes the velocity from v to ....., and hence the momentum from ..... to ...... The total change in momentum is therefore ...... Since rate of change of momentum is equal to force, the force resulting from one molecular impact on the wall per second equals ....., and if x molecules are hitting the wall per second, we obtain the total force exerted by the x molecules: ...... But pressure is ....., and so the pressure of the molecules on the wall of area A is ......

The same method can be tried with mathematical deductions; and once the student realizes that there is no necessity for memorizing the "theory," since he can depend on finding in the statement of the question almost everything that has to be remembered, he will be able to pay more attention to the comprehension of what he reads. Under these conditions it seems admissible to introduce calculus in the first physics course, and certainly in the second course for the nonphysicists. What we need with all scientifically educated persons is a "reading knowledge" of calculus; this applies especially to the biologist or premedical student.

Properly selected numerical problems may be

included in any of these tests or examinations, either in the usual way, or as "guided numerical problems." Such problems should always be stated in the simplest terms, without any paraphrasing. Difficult formulations, double negatives, and so forth, should be avoided, as should questions of the puzzle type. When problems are interspersed (and generally questions should be arranged without regard for order of presentation in the text or degree of difficulty), it is of interest to correlate the results between correctly answered numerical problems and other testing material. One often finds students who solve problems, but show very little reasoning power in other kinds of test. One reason may be that they fail to pay sufficient attention to the latter, being under the impression that problem solving is the most important preparation for the examination. There is as much inertia and conservatism in the young as in the old.

Clearly the history of science, the importance of theories, the philosophical and cultural implications of physics and of science in general, can be tested with all kinds of the aforementioned objective tests. We have always to keep in mind that this is a physics course, and that the cultural material must not be separated from the scientific material, either in the curriculum or in the examination, but should be thoroughly integrated with it. If we should try to test knowledge by problem-type examinations, and set in addition some questions on the cultural ideas involved, we should achieve very little. The student must try to integrate as much as possible by himself, and must accustom himself to seeing the connections and interrelations among experiments, theories and inferences. A question stimulating such an attitude may be stated as follows:

Newton carried out many researches in optics and showed that white light was ...... He regarded a beam of light as a train of ..... which impinged on the retina. At the beginning of the ..... century Young and Fresnel introduced the rival ..... theory again, confirming it by experiments on the ....., ..., and ...... of light. But only when Foucault gave experimental evidence about the ..... of light in various mediums had the ..... theory finally to be discarded.

The answer requires knowledge of scientific facts and of the scientific historical situation. It does not show whether a student knows what polarization of light is, but one can surmise that he understands the role of the experimental evidence in the whole history of the theories of light. Questions on quantum theory, relativity, biophysics, force and mass, energy and momentum, and so on, can all be phrased in simple terms of objective testing material. For example:

The negative outcome of the Michelson-Morley experiment gave one certain result, namely, that with the help of optical, that is, ... experiments, a proof for a ..... motion relative to the ..... space cannot be achieved, just as it is impossible by ..... experiments. In consequence, the conception of a ..... in which light would be propagated and which would fill the ..... had to be ......

To repeat: only if the examination is broadened in the same way as the lecture course will our students pay attention to the ideas we want to impart to them in the modern cultural approach. Otherwise the students will dismiss much of the new material as fancy ideas of the instructor, as some decoration of the "true" subject matter. We may deplore the fact that the students are little inclined to give their thought to philosophy, but these are the facts. With a high percentage of our students of mature age a good response to any endeavor of this kind may be expected at present. The fact that students put the examination before the lecture shows that we are on the right path in recognizing this attitude and turning it to our advantage, which certainly is also the advantage of the students.

Objective examinations are usually rather long and may include up to 100 short questions for a 3-hr test. This seems to be too exacting, and shorter papers with about 40 questions of different lengths may be preferable. Regular tests with a smaller number of questions may give many hints to the lecturer. For the student to see, instead of a dreary problem paper, an objective test paper with its variety of questions, graphs and figures, should make the examination truly enjoyable. If the paper is well constructed there is little danger that a student can pass just by scanning the textbook. On the contrary, we should expect that by these examinations the learning process would be much improved. The average student will not just pick up a few details, or learn how to solve certain types of examples, but will try to see the connections, the

"great problems" of science. The instructor, on the other hand, is relieved from the duty of teaching the students how to "do" examples, and more time is available for the development of a coherent picture of physics in all its essential parts, and for the preparation of impressive and instructive demonstration experiments.

In a first or general physics course we have an assembly of students who have not quite decided what special studies they will follow; their interest when entering college is still liable to change. Students who later enter physics and engineering may find it a disadvantage that the solving of examples is relegated to a lesser role. It is, however, not necessary that the student's instruction in respect of the mathematical part shall suffer. There are several ways of giving additional instruction in calculations; students are usually given very detailed prescriptions for laboratory work, and there can be no objection to giving them also a selection of useful problems in completely worked form.

The time for exhortations is now over; we need practical experience, in teaching and examination procedure, in connection with the new curricular aims. A great help would be the publication of a couple of thousand objective questions for the testing of achievements in a general physics course, and perhaps for a higher level. This would give the instructors useful suggestions and would make the introduction of objective examinations, and with them of cultural physics courses, more popular.

III

The discussion about the role which physics should play in the curriculum of a liberal education, starting where it left off before the war, makes rather melancholy reading. It is not astonishing that many teachers get the impression that a reform of physics teaching finds too many hindrances ever to materialize. However, if surprise is expressed about these statements, one overlooks the fact that physics teaching is not alone in this respect; the difficulties arise in great part from the generally stagnant situation in education with the resulting lack of impetus to reform. The universities and colleges, in general, have found it impossible or inconvenient to adapt their courses to the varying social composition and greater maturity of their students. They do not try to be interpreters of culture. Instead, they evade the "great problems," and they give a technical training, and with the rising demand for experts and specialists they find enough justification in their activities. This is especially unfortunate in physics, whose long history, interesting development, close connection with the thought of centuries, and basic importance for our modern world outlook, can be made to constitute a fundamental educational discipline. The admitted difficulties in giving substance to this potentiality does not exonerate the physics teacher from using physics as an educational vehicle, but on the contrary puts a heavy responsibility on his shoulders.

The one difficulty in enhancing the cultural contents of a physics course is, as I have pointed out previously,[2] the inherent attitude of the physicists to their subject: their deep-rooted philosophy that physics is the basis of our modern culture, that proper thinking and reasoning started only 300 years ago with Galileo, that "superstition" was destroyed by the "sciences," and that only since then has scientific thought begun to shape the whole world, as Comte's philosophy of what we can term "cultural transfer" teaches. In this widely accepted view of history lies the cause of the physics teacher's adherence to the educational theory of transfer, and his conservatism in the classroom.

Today the situation has changed insofar as scientists have become aware of the necessity of bringing their influence to bear on world affairs. After the spectacular and fateful effects of the atomic bomb, and with far-reaching economic changes expected to follow the development of atomic energy, physicists have lost some of their apathy. But with the responsibility for such huge power in their hands, scientists are more inclined to do their educational work on a grand scale, through political channels, and through propaganda. It is to be hoped that attention will still be paid to the educational opportunities open to the science teacher in schools, colleges and universities. This rather slow work should not be overlooked, despite the pressing problems.

[2] O. Blüh, "The contribution of physics to the college curriculum," *Am. J. Physics* **10**, 39 (1942).

Utilizing the Mks System

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THE metric system has been accepted legally by all civilized nations, either as permissible or obligatory.[1] It is thus truly an international system. For many years the particular metric arrangement called cgs (centimeter-gram-second) has played a prominent role in scientific work. But the choice of the centimeter and the gram as fundamental units does not allow a good coordination with the practical electric units. In 1901, G. Giorgi[2] pointed out that the choice of the meter and the kilogram as fundamental units would allow a convenient unification of physical measurements, including electrical measurements in the established practical units. This choice results in the mks (meter-kilogram-second) system.

Many engineers and physicists realize the advantages of the mks system. Particularly since its adoption by the International Electrotechnical Commission[3] in 1935, a considerable amount of engineering work has been computed in the new system and several books have used it exclusively.[4] In examining a number of recent textbooks, however, we have noticed the following peculiarity. The author starts off bravely with his mks banner flying. In the first chapter there is some faltering in the ranks, however, which in later chapters turns into a complete rout. The reason is not far to seek. It seems easier to write in the customary mixture of units than to convert everything into the mks system. This is true particularly when tables of physical constants in mks units are not available.

The purpose of this paper is to show how the mks system unifies all of classical physics. Representative numerical data and conversion factors are also given. There is nothing essentially new in the treatment. We hope, however, that the collection of the necessary information in a condensed form will encourage more writers and teachers to use the mks system.

Mechanics

A list of important concepts in physics and engineering is given in Table I. In most cases, the symbols listed in column two are those recommended by the American Standards Association.[5] To provide different dimensions for units that are conceptually distinct, we have found it convenient to employ[6] the two dimensions $[L_r]$ and $[L_t]$ in place of the usual $[L]$. According to ordinary dimensional theory, the unit of *work* has the same dimensions as the unit of *torque*. Also, the *candle* is identical dimensionally with the *lumen*, and *brightness* is dimensionally indistinguishable from *luminous flux density*. These and other difficulties are eliminated by using $[L_r]$ and $[L_t]$.

In textbooks on physics, and more especially on engineering mechanics, there seems to be considerable confusion regarding *mass* and *weight*. This confusion has been carried over even into

[1] W. Hallock and H. T. Wade, *The evolution of weights and measures and the metric system* (Macmillan, 1906); J. D. Everett, *The cgs system of units* (Macmillan, 1902).

[2] G. Giorgi, "Unità razionali di elettromagnetismo," *Assoc. elettrot. italiana, atti*, **5**, 402 (1901); *Nuovo Cimento* **48**, 11 (1902); "Il sistema assoluto M. Kg. S," *Assoc. elettrot. italiana, atti*, **6**, 453 (1902); "Questioni vive sulla sistemazione delle unità elettrotecnica," *L'Elettrotecnica* **21**, 765 (1934); G. A. Campbell, "A system of definitive units for universal use," *Proc. Int. Math. Congress, Toronto* **2**, 355 (1924); *Science* **61**, 353 (1925); E. E. Bennett, *A digest of the relations between the electrical units and of the laws underlying the units* (Univ. of Wisconsin Bull., 1917).

[3] A. E. Kennelly, "I.E.C. adopts mks system of units," *Trans. AIEE* **54**, 1373 (1935); A. E. Kennelly and Brylinski, "Adoption par la Commission Electrotechnique Internationale du système Giorgi," *Soc. française des Elec., Bull.*, **6**, 47 (1936); O. Garavaldi, "Le decisioni della Commissione Electrotecnica Internazionale e l'adozione del sistema Giorgi per le unità fisiche," *Nuovo Cimento* **13**, 455 (1935).

[4] Among the books that make exclusive use of the mks system may be mentioned J. A. Stratton, *Electromagnetic theory* (McGraw-Hill, 1941).

[5] Report No. 3 of the Committee on Letter Symbols and Abbreviations, "Proposal to standardize letter symbols," *Am. J. Physics* **8**, 300 (1940); *Proposed American standard letter symbols for physics* (Am. Standards Assn., in press).

[6] P. Moon, "A system of photometric concepts," *J. Opt. Soc. Am.* **32**, 348 (1942).

TABLE I. Important concepts in physics and engineering.

Concept	Symbol	Defining equation	Dimensions of unit	Mks unit
		(a) Mechanics		
Kinematics				
Distance	s		$[L_r]$	m
Area	A	$=s^2$	$[L_t^2]$	m^2
Volume	V	$=s^3$	$[L_rL_t^2]$	m^3
Time	t		$[T]$	sec
Velocity	$\mathbf{v}$	$=\mathrm{d}\mathbf{s}/\mathrm{d}t$	$[L_rT^{-1}]$	$\mathrm{m\ sec^{-1}}$
Acceleration	$\mathbf{a}$	$=\mathrm{d}\mathbf{v}/\mathrm{d}t$	$[L_rT^{-2}]$	$\mathrm{m\ sec^{-2}}$
Angle	θ		$[L_tL_r^{-1}]$	rad
Solid angle	$d\Omega$	$=\mathrm{d}a/r^2$	$[L_t^2L_r^{-2}]$	ster
Angular velocity	ω	$=\mathrm{d}\theta/\mathrm{d}t$	$[L_tL_r^{-1}T^{-1}]$	$\mathrm{rad\ sec^{-1}}$
Angular acceleration	α	$=\mathrm{d}\omega/\mathrm{d}t$	$[L_tL_r^{-1}T^{-2}]$	$\mathrm{rad\ sec^{-2}}$
Wavelength	λ		$[\Lambda]$	micron $[\equiv 10^{-6}\ \mathrm{m}]$
Period	t		$[T]$	sec
Frequency	f	$=1/t$	$[T^{-1}]$	hertz
Dynamics				
Mass	m		$[M]$	kg
Force	$\mathbf{F}$	$=m\mathbf{a}$	$[ML_rT^{-2}]$	newton
Weight	$\mathbf{w}$	$=m\mathbf{g}$	$[ML_rT^{-2}]$	newton
Torque	$\mathcal{T}$	$=\mathbf{F}\times\mathbf{s}$	$[ML_rL_tT^{-2}]$	newton m
Moment of Inertia	$\mathcal{I}$	$=\int r^2\mathrm{d}m$	$[ML_r^2]$	$\mathrm{kg\ m^2}$
Momentum		$m\mathbf{v}$	$[ML_rT^{-1}]$	$\mathrm{kg\ m\ sec^{-1}}$
Impulse		$\int\mathbf{F}\mathrm{d}t$	$[ML_rT^{-1}]$	newton sec
Energy	U		$[ML_r^2T^{-2}]$	joule
Kinetic energy	U_k	$=\frac{1}{2}mv^2$	$[ML_r^2T^{-2}]$	joule
Potential energy	U_p	$=mgh$	$[ML_r^2T^{-2}]$	joule
Work	U	$=\int\mathbf{F}\cdot\mathrm{d}\mathbf{s}$	$[ML_r^2T^{-2}]$	joule
Power	P	$=\mathrm{d}U/\mathrm{d}t$	$[ML_r^2T^{-3}]$	watt
Elasticity				
Pressure	p	$=F/A$	$[ML_rL_t^{-2}T^{-2}]$	$\mathrm{newton\ m^{-2}}$
Stress, normal	T	$=F/A$	$[ML_rL_t^{-2}T^{-2}]$	$\mathrm{newton\ m^{-2}}$
shear	T		$[ML_tT^{-2}]$	$\mathrm{newton\ m^{-2}}$
Strain, normal	S	$=\Delta s/s$	0	
shear	S		$[L_rL_t^{-1}]$	
Elastic modulus	c	$=T/S$	$[ML_rL_t^{-2}T^{-2}]$	$\mathrm{newton\ m^{-2}}$
Density	D	$=m/V$	$[ML_r^{-1}L_t^{-2}]$	$\mathrm{kg\ m^{-3}}$
		(b) Heat		
Temperature	T		$[\Theta]$	deg
Thermal energy	U		$[ML_r^2T^{-2}]$	joule
Thermal power	P	$=\mathrm{d}U/\mathrm{d}t$	$[ML_r^2T^{-3}]$	watt
Specific heat	c	$=\mathrm{d}U/m\mathrm{d}t$	$[L_r^2T^{-2}\Theta^{-1}]$	$\mathrm{joule\ kg^{-1}\ deg^{-1}}$
Conductivity	k	$=P/(A\mathrm{d}t/\mathrm{d}s)$	$[ML_r^3L_t^{-2}T^{-3}\Theta^{-1}]$	$\mathrm{watt\ m^{-1}\ deg^{-1}}$
Diffusivity	h^2	$=k/(cD)$	$[L_r^2T^{-1}]$	$\mathrm{m^2\ sec^{-1}}$
Emissivity	$\mathfrak{e}$	$=P/(AT)$	$[M\Theta^{-1}T^{-3}]$	$\mathrm{watt\ m^{-2}\ deg^{-1}}$
Entropy	$\mathcal{S}$	$=\int\mathrm{d}U/T$	$[ML_r^2T^{-2}\Theta^{-1}]$	$\mathrm{joule\ deg^{-1}}$

the mks system. It seems to be particularly troublesome in countries where the metric system is obligatory and where injudicious technicians have sometimes employed the kilogram as the unit of force instead of as the unit of mass.

Weight is a concept that should never have been invented. If it is used, however, it must be expressed in units of force (*newtons*, in the mks system), not in units of mass. The example of the pound weight, pound mass, poundal, and slug of the British system[7] should warn any scientist against introducing a similar, unnecessary and maddening complexity into the mks system. When the distinction is always clearly drawn between mass and weight, the student finds no difficulty in grasping the subject. But when the textbook never draws a clear distinction between the two ideas and employs the two words more or less interchangeably, there is sure to be trouble. *Only one mks system is internationally sanctioned: in this system the kilogram is the unit of mass, not the unit of force or weight.*

[7] L. A. Hawkins and S. A. Moss, "Alice and the sluggers," *Am. J. Physics* **13**, 409 (1945).

Heat

In Table I(b), the only concept needing comment is *thermal energy*. Since mechanical energy,

TABLE I.—*Continued.*

Concept	Symbol	Defining equation	Dimensions of unit	Mks unit
		(c) Electricity and magnetism		
Charge	Q		$[Q]$	coul
Charge per unit length	ɔ	$=Q/s$	$[QL_r^{-1}]$	coul m^{-1}
Charge per unit area	ɥ	$=Q/A$	$[QL_t^{-2}]$	coul m^{-2}
Charge per unit volume	ʎ	$=Q/V$	$[QL_r^{-1}L_t^{-2}]$	coul m^{-3}
Electric field strength	$\mathbf{E}$	$=d\mathbf{F}/dQ$	$[ML_rT^{-2}Q^{-1}]$	volt m^{-1}
Electric flux density	$\mathbf{D}$	$\int \mathbf{D}\cdot d\mathbf{A}=Q$	$[QL_t^{-2}]$	coul m^{-2}
Permittivity	ϵ	$=D/E$	$[M^{-1}L_r^{-1}L_t^{-2}T^2Q^2]$	farad m^{-1}
Potential	φ	$=\int \mathbf{E}\cdot d\mathbf{s}$	$[ML_r^2T^{-2}Q^{-1}]$	volt
Potential difference	V	$=\varphi_A-\varphi_B$	$[ML_r^2T^{-2}Q^{-1}]$	volt
Capacitance	C	$=Q/V$	$[M^{-1}L_r^{-2}T^2Q^2]$	farad
Electric dipole moment	p	$=Qs$	$[L_rQ]$	coul m
Electric current				
Current	I	$=dQ/dt$	$[QT^{-1}]$	amp
Current density	u	$=dI/dA$	$[QL^{-2}T^{-1}]$	amp m^{-2}
Electro-chemical equivalent	z	$=m/Q$	$[MQ^{-1}]$	kg $coul^{-1}$
Resistivity	ρ	$=RA/l$	$[ML_rL_t^2T^{-1}Q^{-2}]$	ohm m
Conductivity	σ	$=1/\rho$	$[M^{-1}L_r^{-1}L_t^{-2}TQ^2]$	mho m^{-1}
Resistance	R	$=V/I$	$[ML_r^2T^{-1}Q^{-2}]$	ohm
Conductance	G	$=1/R$	$[M^{-1}L_r^{-2}TQ^2]$	mho
Magnetic field				
Magnetic field strength	$\mathbf{H}$	$\oint \mathbf{H}\cdot d\mathbf{s}=NI$	$[QL_t^{-1}T^{-1}]$	amp turn m^{-1}
Magnetomotive force	F	$=NI$	$[QT^{-1}]$	amp turn
Magnetic flux density	$\mathbf{B}$	$d\mathbf{F}=I(d\mathbf{s}\times\mathbf{B})$	$[ML_rL_t^{-1}Q^{-1}T^{-1}]$	weber m^{-2}
Magnetic flux	Φ	$=\int \mathbf{B}\cdot d\mathbf{A}$	$[ML_rL_tQ^{-1}T^{-1}]$	weber
Permeability	μ	$=B/H$	$[ML_rQ^{-2}]$	henry m^{-1}
Reluctance	$\mathcal{R}$	$=F/\Phi$	$[M^{-1}L_r^{-1}L_t^{-1}Q^2]$	amp turn $weber^{-1}$
Inductance	L	$=N\Phi/I$	$[ML_rL_tQ^{-2}]$	henry
Magnetic dipole moment	m	$=NIA$	$[L_r^2T^{-1}Q]$	amp m^2
		(d) Radiometry and photometry		
Radiometry				
Radiant pharos	F_r		$[P]$	watt
Radiant pharosage	D_r	$=F_r/A$	$[PL_t^{-2}]$	watt m^{-2}
Radiant phos	Q_r	$=F_rt$	$[PT]$	watt sec
Radiant phosage	U_r	$=Q_r/A$	$[PTL_t^{-2}]$	watt sec m^{-2}
Radiant helios	H_r	$=\pi \lim_{\omega\to 0} D_{rm}/\omega$	$[PL_t^{-4}L_r^2]$	herschel
Radiant heliosent	G_r	$=\lim_{\Delta l\to 0} \Delta H_r/\Delta l$	$[PL_t^{-4}L_r]$	herschel m^{-1}
Phengosage	$J(\lambda)$	$=\lim_{\Delta\lambda\to 0} \Delta D_r/\Delta\lambda$	$[PL_t^{-2}\Lambda^{-1}]$	watt m^{-2} $micron^{-1}$
Photometry				
Luminous pharos	F_l		$[F]$	lumen
Luminous pharosage	D_l	$=F_l/A$	$[FL_t^{-2}]$	lumen m^{-2}
Luminous phos	Q_l	$=F_lt$	$[FT]$	lumen sec
Luminous phosage	U_l	$=Q_l/A$	$[FTL_t^{-2}]$	lumen sec m^{-2}
Luminous helios	H_l	$=\pi \lim_{\omega\to 0} D_{lm}/\omega$	$[FL_t^{-4}L_r^2]$	blondel
Luminous heliosent	G_l	$=\lim_{\Delta l\to 0} \Delta H_l/\Delta l$	$[FL_t^{-4}L_r]$	blondel m^{-1}
Connectives				
Spectral lamprosity	$\bar{y}(\lambda)$	$=D_l(\lambda)/D_r(\lambda)$	$[FP^{-1}]$	lumen $watt^{-1}$
Total lamprosity	$\bar{y}_t$	$=D_l/D_r$	$[FP^{-1}]$	lumen $watt^{-1}$
Actance	η	$=F_l/P$	$[FP^{-1}]$	lumen $watt^{-1}$
Colorimetry				
Trichromatic weighting functions	$\bar{x}(\lambda)$		$[F_xP^{-1}]$	könig $watt^{-1}$
	$\bar{y}(\lambda)$		$[FP^{-1}]$	young $watt^{-1}$
	$\bar{z}(\lambda)$		$[F_zP^{-1}]$	priest $watt^{-1}$
Trichromatic coordinates	X	$=\int \bar{x}(\lambda)J(\lambda)d\lambda$	$[F_xL_t^{-2}]$	könig m^{-2}
	Y	$=\int \bar{y}(\lambda)J(\lambda)d\lambda$	$[FL_t^{-2}]$	young m^{-2}
	Z	$=\int \bar{z}(\lambda)J(\lambda)d\lambda$	$[F_zL_t^{-2}]$	priest m^{-2}

TABLE II. Some common measures in everyday life and their approximate equivalents in mks units.

	English system	Mks
Length		
Height of a man	5 ft, 11 in.	1.8 m
One mile	1 mi	1.6 km
Mass		
Mass of a person	130 lb	60 kg
One pound	1 lb	0.454 kg
Volume		
One quart	1 qt	0.001 m^3
One bushel	1 bu	0.035 m^3
Velocity	45 mi hr^{-1}	20 m sec^{-1}
Force		
Force of gravity on 1-lb mass	1 lb	4.45 newton

TABLE III. Important physical constants (Based on R. T. Birge, reference 12).

Velocity of light, c	2.99776×10^8 m sec^{-1}
Gravitational constant, G	6.670×10^{-11} newton m^2kg^{-2}
Ice point, T_0	273.16°K
Mechanical equivalent of heat, J	4.182 joule cal^{-1}
Electronic charge, q	1.6008×10^{-19} coul
Mass of electron, m	9.1066×10^{-31} kg
Average density of the earth, D	5517 kg m^{-3}
Acceleration of gravity (standard), g	9.80665 m sec^{-2}
Normal atmosphere, p_0	1.013246×10^5 newton m^{-2}
Boltzmann constant, k	1.38047×10^{-23} joule deg^{-1}
Permittivity of free space, ϵ_0	8.854×10^{-12} farad m^{-1}
Permeability of free space, μ_0	$4\pi\times10^{-7}$ henry m^{-1}

TABLE IV. Elastic moduli at 20°C.

Material	Young's modulus (newton m^{-2})	Shear modulus (newton m^{-2})	Volume modulus (newton m^{-2})
Aluminum	7×10^{10}	2.5×10^{10}	7.4×10^{10}
Brass	9.2	3.7	6.1
Copper	10	4.2	12.0
German silver	10.8	4.5	15.0
Glass, crown	7.0	2.9	5.0
flint	5.5	2.2	3.7
Gold	8.0	3.0	16.0
Lead	1.7	0.7	0.76
Magnesium	4.2	1.7	—
Manganin	12.4	4.6	12.1
Nickel	22.0	8.0	17.0
Platinum	17.0	6.5	24.0
Silver	7.5	2.7	10.0
Steel, soft	22.0	8.0	16.0
Tin	5.0	2.0	5.0
Zinc	9.0	3.4	3.5

thermal energy, and electromagnetic energy are all special forms of the same thing, they should all be called *energy* and should all be expressed in the same unit. The idea of employing a different unit (calorie, Btu) for energy in the thermal form is a relic from the days when no connection was known between heat and mechanical energy.

TABLE V. Density and thermal constants, representative values at room temperature.

Material	Conductivity, k (watt m^{-1} deg^{-1})	Specific heat, c (joule kg^{-1} deg^{-1})	Density, D (kg m^{-3})	Diffusivity, h^2 (m^2 sec^{-1})
Metals				
Aluminum	200	895	2710	82.6×10^{-6}
Brass	85	310	8500	32.3
Copper	384	383	8800	113
Gold	293	129	19210	118
Iron, wrought	60	444	7850	17.3
cast	45	477	7100	13.3
Lead	35	129	11320	23.9
Magnesium	158	1030	1740	88.2
Manganin	64	406	8500	18.5
Mercury	6.2	140	13550	3.27
Nickel	59	444	8810	15.1
Platinum	70	134	21390	24.4
Silver	420	230	10530	173
Silicon steel	50	450	7600	14.7
Tin	65	219	7280	40.8
Tungsten	146	151	19100	50.6
Zinc	110	386	7110	40.0
Other materials				
Air	0.023	990	1.29	18.0
Asbestos (loose)	0.17	840	2200	0.092
Brick, common	0.84	750	2000	0.56
firebrick	1.7	750	2000	1.13
Cardboard	0.21	—	—	—
Coal	0.34	840	1500	0.27
Coil (electrical, average)	0.50	—	—	—
Concrete	0.92	670	2370	0.58
Cork (ground)	0.050	2000	150	0.17
Cotton (loose)	0.063	—	—	—
Cotton tape (varnished)	0.15	—	—	—
Earth, average	1.5	1890	1650	0.48
dry	0.37	—	—	0.31
Glass	1.0	670	2600	0.57
Granite	3.4	820	2660	1.56
Gutta percha	0.20	—	—	—
Hard rubber	0.17	1420	1150	0.10
Ice (at 0°C)	2.2	2100	920	1.14
Insulation (av. for elec. machines)	0.20	—	—	—
Limestone	2.1	910	2700	0.85
Mica	0.36	870	2900	0.14
Paraffin	0.26	2900	900	0.10
Porcelain	1.0	1100	2400	0.38
Rock (av.)	1.9	1050	2800	0.65
Sandstone	2.1	900	2200	1.10
Snow (fresh)	0.13	2100	180	0.34
Water	0.60	4186	1000	0.143
Wood, pine, across grain	0.038	1380	400	0.069
pine, along grain	0.13	1380	400	0.23
Wool	0.059	1640	—	—

TABLE VI. Heat of fusion.

Material	Melting point (°C)	Heat of fusion (joule kg^{-1})
Aluminum	657	39×10^4
Copper	1083	20.6
Gold	1063	6.65
Iron, cast	1200	9.6
Lead	327	2.5
Magnesium	650	30.0
Mercury	−38.9	1.16
Nickel	1450	3.0
Paraffin	52.4	14.6
Platinum	1755	11.4
Silver	960	10.8
Sulphur	115	3.9
Tin	232	6.0
Water	0	33.3
Zinc	420	11.1

TABLE VII. Electrical resistivity at 20°C.

Material	Resistivity, ρ (ohm m)	Temperature coefficient (deg^{-1})
Aluminum	2.83×10^{-8}	3.9×10^{-3}
Brass	7.0	2.0
Copper, annealed std.	1.724	3.93
hard drawn	1.77	3.82
German silver	33	0.4
Gold	2.44	3.4
Lead	22	3.9
Manganin	44	0
Mercury	96	0.89
Nichrome	99.6	0.44
Nickel	7.8	6.0
Platinum	10	3.0
Silver	1.6	3.8
Steel, hard	47.2	1.6
4 percent Si	62	0.8
soft	17.4	4.2
Tantalum	15.5	3.1
Tin	11.5	4.2
Tungsten	5.51	5.1
Zinc	6.3	4.0

TABLE VIII. Permittivity at 20°C, in farads per meter.

Free space	8.854×10^{-12}
Air (0°C, 10^5 newton m^{-2})	8.859
Asbestos paper	23.9
Cellophane	71
Celluloid	120
Cellulose acetate	44
Glass, flint	87
crown	62
lead	58
Glycerin	500
Gutta percha	36
Hard rubber	24
Mica	51
Paraffin	19
Polystyrene	23
Porcelain	51
Pyranol	44
Rubber	22
Transformer oil	22
Water, pure	720

Thus one of the obvious simplifications in international physics and technology is the use of the *joule* (*watt second*) *for all forms of energy and the watt for all forms of power*. The only possible advantage to the calorie or the British thermal unit is in the special case of the heating of water. But the heating of water occupies a much smaller place in world affairs than one might infer from reading elementary books on physics and chemistry. In nearly all problems of thermodynamics, heat conduction and solar radiation, the watt and the joule are more convenient than the calorie. If these mks units are employed, specific heat is expressed in joules per kilogram degree and thermal conductivity in watts per meter degree, as has been done for many years by practical electrical engineers.

Electricity and Magnetism

Table I(c) shows that the mks units of electricity and magnetism are the usual practical units that are employed throughout the world by electrical engineers. The units of Table I(c) *belong to the so-called rationalized system*. Rationalization was suggested by Oliver Heaviside; its purpose is to simplify the equations that are employed most frequently in practice. The rationalized mks system was advocated by Giorgi[3] and other eminent scientists and has been used in recent books.[4]

In the rationalized mks system, the permittivity of free space is

$$\epsilon_0 = 8.854\times10^{-12}\ \text{farad m}^{-1},$$

and the permeability of free space is

$$\mu_0 = 4\pi\times10^{-7}\ \text{henry m}^{-1}.$$

Just as water has lost its preferred position in modern heat theory, so free space has lost its unique characteristic of $\epsilon=\mu=1$ which it had in the cgs system. This change is mourned, perhaps,

TABLE IX. Properties of alloy steels for electrical apparatus.

Material	Saturation B (weber m^{-2})	μ_{max} (henry m^{-1})	μ for $B\to0$ (henry m^{-1})	ρ (ohm m)	Core loss* (watt kg^{-1})
Purified iron	2.15	346×10^{-3}	31×10^{-3}	—	excessive
Permalloy (78.5% Ni)	1.07	132	11	16×10^{-8}	0.75
Hipernik (50% Ni)	1.50	110	7.5	35	0.44
Mumetal	0.85	100	8.8	25	—
Silicon steel (4% Si)	1.90	10	0.95	60	1.3
Silicon steel (1.0% Si)	2.10	6.5	0.44	24	2.6
Soft steel (0% Si)	2.10	4.4	0.38	11	4.6

* At 60 hertz and $B_{max}=1.0$ weber m^{-2}.

TABLE X. Conversion factors.

Name	Multiply number of	by	To obtain number of
Distance, s	m	10^2	cm
		39.370	in.
		3.2808	ft
		1.0936	yd
		10^{-3}	km
		6.2136×10^{-4}	mi
	cm	10^{-2}	m
	in.	2.5400×10^{-2}	
	ft	0.30480	
	yd	0.91440	
	km	10^3	
	mi	1609.4	
Area, A	m^2	10^4	cm^2
		1550.0	in.^{2}
		10.764	ft^2
		1.1960	yd^2
		10^{-6}	km^2
		3.8610×10^{-7}	mi^2
	cm^2	10^{-4}	m^2
	in.^{2}	6.4516×10^{-4}	
	ft^2	9.2903×10^{-2}	
	yd^2	0.83613	
	km^2	10^6	
	mi^2	2.590×10^6	
Volume, V	m^3	10^6	cm^3
		6.1023×10^4	in.^{3}
		999.973	liter
		35.314	ft^3
		1.3079	yd^3
		264.17	gallon
	cm^3	10^{-6}	m^3
	in.^{3}	1.6387×10^{-5}	
	liter	10^{-3}	
	ft^3	2.8317×10^{-2}	
	yd^3	0.76456	
	gallon	3.7854×10^{-3}	
Time, t	sec	1.6667×10^{-2}	min
		2.7778×10^{-4}	hr
		1.1574×10^{-5}	day
	min	60	sec
	hour	360	
	day	8.6164×10^4	
Velocity, v	m sec^{-1}	102	cm sec^{-1}
		3.2808	ft sec^{-1}
		3.6000	km hr^{-1}
		2.2369	mi hr^{-1}
	cm sec^{-1}	10^{-2}	m sec^{-1}
	ft sec^{-1}	0.30480	
	km hr^{-1}	0.27778	
	mi hr^{-1}	0.44704	
Acceleration, a	m sec^{-2}	10^2	cm sec^{-2}
		3.2808	ft sec^{-2}
	cm sec^{-2}	10^{-2}	m sec^{-2}
	ft sec^{-2}	0.30480	
Angle, θ	rad	57.296	deg
	deg	1.7453×10^{-2}	rad
Angular velocity, ω	rad sec^{-1}	0.1592	rev sec^{-1}
		9.549	rev min^{-1}
		57.30	deg sec^{-1}
	rev sec^{-1}	6.283	rad sec^{-1}
	rev min^{-1}	0.1047	
	deg sec^{-1}	0.01745	

Angular acceleration, α	rad sec^{-2}	57.30	deg sec^{-2}
		0.1592	rev sec^{-2}
		573.0	rev min^{-2}
	deg sec^{-2}	0.01745	rad sec^{-2}
	rev sec^{-2}	6.283	
	rev min^{-2}	1.745×10^{-3}	
Wavelength, λ	micron (μ)	10^{-6}	m
		10^{-4}	cm
		10^{-3}	mm
		10^{3}	mμ
		10^{4}	A
	m	10^{6}	micron (μ)
	cm	10^{4}	
	mm	10^{3}	
	mμ	10^{-3}	
	A	10^{-4}	
Mass, m	kg	10^{3}	gm
		0.068521	slug
		2.2046	lb (mass)
		35.274	oz
	gm	10^{-3}	kg
	slug	14.594	
	lb	0.45359	
	oz	0.028349	
Force, F	newton	10^{5}	dyne
		7.2327	poundal
		0.22481	lb (force)
	dyne	10^{-5}	newton
	poundal	0.13826	
	lb (force)	4.4482	
Weight, w	newton	10^{5}	dyne
		7.2327	poundal
		0.22481	lb (force)
	dyne	10^{-5}	newton
	poundal	0.13826	
	lb (force)	4.4482	
Torque, $\mathcal{T}$	newton m	10^{7}	dyne cm
		0.73756	lb ft
	dyne cm	10^{-7}	newton m
	lb ft	1.3558	
Moment of inertia, $\mathcal{I}$	kg m^2	10^{7}	g cm^2
		23.730	lb ft^2
		3417.1	lb $in.^2$
	g cm^2	10^{-7}	kg m^2
	lb ft^2	0.042141	
	lb $in.^2$	2.9265×10^{-4}	
Momentum, mv	kg m sec^{-1}	10^{5}	gm cm sec^{-1}
		7.233	lb ft sec^{-1}
	gm cm sec^{-1}	10^{-5}	kg m sec^{-1}
	lb ft sec^{-1}	0.1383	
Impulse, $\int F dt$	newton sec	10^{5}	dyne sec
		0.2248	lb sec
	dyne sec	10^{-5}	newton sec
	lb sec	4.448	
Energy, U	watt sec	10^{7}	erg
	(joule)	1	watt sec
		2.788×10^{-4}	watt hr
		2.778×10^{-7}	kwh
		0.2391	cal
		0.7375	ft lb
		9.480×10^{-4}	Btu
	erg	10^{-7}	watt sec (joule)
	watt sec	1	
	watt hr	3600	
	kwh	3.6×10^{6}	
	cal	4.182	
	ft lb	1.356	
	Btu	1055	

Power, P	watt	10^{-3}	kw
		10^{7}	erg sec^{-1}
		0.2391	cal sec^{-1}
		14.35	cal min^{-1}
		0.7375	ft lb sec^{-1}
		44.25	ft lb min^{-1}
		0.05688	Btu min^{-1}
		3.413	Btu hr^{-1}
	kilowatt	10^{3}	watt
	erg sec^{-1}	10^{-7}	
	cal sec^{-1}	4.182	
	cal min^{-1}	0.06969	
	ft lb sec^{-1}	1.356	
	ft lb min^{-1}	0.02260	
	Btu min^{-1}	17.58	
	Btu hr^{-1}	0.2930	
Pressure, p	newton m^{-2}	10	dyne cm^{-2}
		0.02088	lb ft^{-2}
		1.450×10^{-4}	lb in.$^{-2}$
		2.131×10^{-3}	atm
		7.500×10^{-2}	cm-Hg
		2.953×10^{-2}	in-Hg
		3.333×10^{-2}	ft-water
		10^{-5}	bar
	dyne cm^{-2}	10^{-1}	newton m^{-2}
	lb ft^{-2}	47.88	
	lb in.$^{-2}$	6.895×10^{3}	
	atm	469.2	
	cm-Hg	13.33	
	in.-Hg	33.86	
	ft water	30.00	
	bar	10^{5}	
Density, D	kg m^{-3}	10^{-3}	gm cm^{-3}
		6.243×10^{-2}	lb ft^{-3}
	gm cm^{-3}	10^{3}	kg m^{-3}
	lb ft^{-3}	16.018	
Specific heat, c	joule kg^{-1} °C^{-1}	2.391×10^{-4}	cal gm^{-1} °C^{-1}
		2.389×10^{-4}	Btu lb^{-1} °F^{-1}
	cal gm^{-1} °C^{-1}	4182	joule kg^{-1} °C^{-1}
	Btu lb^{-1} °F^{-1}	4186	
Conductivity, k	watt m^{-1} °C^{-1}	2.391×10^{-3}	cal sec^{-1} cm^{-1} °C^{-1}
		1.605×10^{-4}	Btu sec^{-1} ft^{-1} °F^{-1}
	cal sec^{-1} cm^{-1} °C^{-1}	418.2	
	Btu sec^{-1} ft^{-1} °F^{-1}	6229	
Diffusivity, h^2	m^{2} sec^{-1}	10^{-4}	cm^{2} sec^{-1}
		10.76	ft^{2} sec^{-1}
	cm^{2} sec^{-1}	10^{-4}	m^{2} sec^{-1}
	ft^{2} sec^{-1}	9.290×10^{-2}	
Emissivity, $\mathfrak{e}$	watt m^{-2} °C^{-1}	2.391×10^{-4}	cal sec^{-1} cm^{-2} °C^{-1}
		4.893×10^{-5}	Btu sec^{-1} ft^{-2} °F^{-1}
	cal sec^{-1} cm^{-2} °C^{-1}	4182.0	watt m^{-2} °C^{-1}
	Btu sec^{-1} ft^{-2} °F^{-1}	2.0436×10^{4}	
Entropy, $\mathcal{S}$	joule °C^{-1}	0.2391	cal °C^{-1}
		5.267×10^{-4}	Btu °F^{-1}
	cal °C^{-1}	4.182	joule °C^{-1}
	Btu °F^{-1}	1.8986×10^{3}	
Charge, Q	coul	3×10^{9}	statcoul (esu)
		10^{-1}	abcoul (emu)
	statcoul (esu)	3.3333×10^{-10}	coul
	abcoul (emu)	10	
Charge density, λ	coul m^{-3}	10^{-6}	coul cm^{-3}
		3000	statcoul cm^{-3}
	coul cm^{-3}	10^{6}	
	statcoul cm^{-3}	3.3333×10^{-4}	

Electric field strength, E	volt m^{-1}	10^{-2}	volt cm^{-1}
		10^{6}	microvolt m^{-1}
		3.333×10^{-5}	dyne $statcoul^{-1}$ (esu)
	volt cm^{-1}	10^{2}	volt m^{-1}
	microvolt m^{-1}	10^{-6}	
	dyne $statcoul^{-1}$ (esu)	3×10^{4}	
Electric flux density, D	coul m^{-2}	$12\pi\times10^{5}$	esu
		$4\pi\times10^{-5}$	emu
	esu	$1/(12\pi\times10^{5})$	coul m^{-2}
	emu	$10^{5}/4\pi$	
Permittivity, ϵ	farad m^{-1}	$36\pi\times10^{9}$	esu
	esu	$1/(36\pi\times10^{9})$ $=8.854\times10^{-12}$	farad m^{-1}
Potential, potential difference, φ, V	volt	$\frac{1}{3}\times10^{-2}$	statvolt (esu)
		10^{8}	abvolt (emu)
	statvolt (esu)	300	volt
	abvolt (emu)	10^{-8}	
Capacitance, C	farad	9×10^{11}	statfarad (cgs)
		10^{-9}	abfarad
	statfarad (cgs)	$1/(9\times10^{11})$	
	abfarad	10^{9}	
Electric dipole moment, p	coul m	3×10^{11}	statcoul cm (esu)
		10	abcoul cm (emu)
	statcoul cm (esu)	$1/(3\times10^{11})$	coul m
	abcoul cm (emu)	10^{-1}	
Current, I	amp	3×10^{9}	statamp (esu)
		10^{-1}	abamp (emu)
	statamp (esu)	$1/(3\times10^{9})$	amp
	abamp (emu)	10	
Current density, u	amp m^{-2}	3×10^{5}	statamp cm^{-2} (esu)
		10^{-5}	abamp cm^{-2} (emu)
	statamp cm^{-2} (esu)	$1/(3\times10^{5})$	amp m^{-2}
	abamp cm^{-2} (emu)	10^{5}	
Electrochemical equivalent, z	kg $coul^{-1}$	10^{3}	g $coul^{-1}$
	g $coul^{-1}$	10^{-3}	kg $coul^{-1}$
Magnetomotive force, F	amp turn	$4\pi\times10^{-1}$	gilbert (emu)
		$12\pi\times10^{9}$	esu
	gilbert (emu)	$10/4\pi$	amp turn
	esu	$1/(12\pi\times10^{9})$	
Magnetic flux density, B	weber m^{-2}	10^{4}	gauss (emu)
		6.452×10^{4}	line $in.^{-2}$
		$1/(3\times10^{6})$	esu
	gauss (emu)	10^{-4}	weber m^{-2}
	line $in.^{-2}$	1.550×10^{-5}	
	esu	3×10^{6}	
Magnetic flux, Φ	weber	10^{8}	maxwell (emu)
		$1/(3\times10^{2})$	esu
	maxwell (emu)	10^{-8}	weber
	esu	3×10^{2}	
Resistivity, ρ	ohm m	10^{2}	ohm cm
		10^{8}	microhm cm
		6.015×10^{8}	ohm/mil-ft
	ohm cm	10^{-2}	ohm m
	microhm cm	10^{-8}	
	ohm/mil-ft	1.662×10^{-9}	
Resistance, R	ohm	1.112×10^{-12}	statohm (esu)
		10^{9}	abohm (emu)
	statohm (esu)	8.988×10^{11}	ohm
	abohm (emu)	10^{-9}	

Magnetic field strength, H	amp turn m^{-1}	10^{-2}	amp turn cm^{-1}
		2.540×10^{-2}	amp turn in.$^{-1}$
		$4\pi\times10^{-3}$	oersted (emu)
	amp turn cm^{-1}	10^{2}	amp turn m^{-1}
	amp turn in.$^{-1}$	39.37	
	oersted (emu)	$10^{3}/\pi$	
Permeability, μ	henry m^{-1}	$10^{7}/\pi$	emu
	emu	$4\pi\times10^{-7}$	henry m^{-1}
Inductance, L	henry	10^{9}	abhenry (emu)
		$1/(9\times10^{11})$	stathenry (esu)
	abhenry (emu)	10^{-9}	henry
	stathenry (esu)	9×10^{11}	
Magnetic dipole moment, m	amp m^{-2}	3×10^{5}	statamp cm^{-2} (esu)
		10^{-5}	abamp cm^{-2} (emu)
	statamp cm^{-2} (esu)	$1/(3\times10^{5})$	amp m^{-2}
	abamp cm^{-2} (emu)	10^{5}	
Radiant pharos, F_r (radiant power)	watt	10^{-3}	kw
		10^{7}	erg sec^{-1}
		0.2391	cal sec^{-1}
		14.35	cal min^{-1}
		0.7375	ft lb sec^{-1}
		44.25	ft lb min^{-1}
		0.05688	Btu min^{-1}
		3.413	Btu hr^{-1}
	kw	10^{3}	watt
	erg sec^{-1}	10^{-7}	
	cal sec^{-1}	4.182	
	cal min^{-1}	0.06969	
	ft lb sec^{-1}	1.356	
	ft lb min^{-1}	0.02260	
	Btu min^{-1}	17.58	
	Btu hr^{-1}	0.2930	
Radiant pharosage, D_r (radiant flux density)	watt m^{-2}	10^{-4}	watt cm^{-2}
		0.09290	watt ft^{-2}
		6.452×10^{-4}	watt in.$^{-2}$
		10^{-3}	kw m^{-2}
		9.290×10^{-5}	kw ft^{-2}
		10^{3}	erg sec^{-1} cm^{-2}
		2.391×10^{-5}	cal sec^{-1} cm^{-2}
		1.435×10^{-3}	cal min^{-1} cm^{-2}
		0.06852	ft lb sec^{-1} ft^{-2}
		4.111	ft lb min^{-1} ft^{-2}
		5.284×10^{-3}	Btu min^{-1} ft^{-2}
		0.3171	Btu hr^{-1} ft^{-2}
	watt cm^{-2}	10^{4}	watt m^{-2}
	watt ft^{-2}	10.764	
	watt in.$^{-2}$	1550	
	kw m^{-2}	10^{3}	
	kw ft^{-2}	10764	
	erg sec^{-1} cm^{-2}	10^{-3}	
	cal sec^{-1} cm^{-2}	4.182×10^{4}	
	cal min^{-1} cm^{-2}	697.0	
	ft lb sec^{-1} ft^{-2}	14.60	
	ft lb min^{-1} ft^{-2}	0.2433	
	Btu min^{-1} ft^{-2}	189.2	
	Btu hr^{-1} ft^{-2}	3.154	
Radiant phos, Q_r (radiant energy)	watt sec	2.778×10^{-4}	watt hr
		2.778×10^{-7}	kw hr
		1	joule
		10^{7}	erg
		0.2391	cal
		0.7375	ft lb
		9.480×10^{-4}	Btu
	watt hr	3600	watt sec
	kw hr	3.6×10^{6}	
	joule	1	
	erg	10^{-7}	
	cal	4.182	
	ft lb	1.356	
	Btu	1055	

Radiant phosage, U_r (radiant energy per unit area)	watt sec m^{-2}	2.778×10^{-4}	watt hr m^{-2}
		2.581×10^{-5}	watt hr ft^{-2}
		2.778×10^{-7}	kw hr m^{-2}
		2.581×10^{-8}	kw hr ft^{-2}
		1	joule m^{-2}
		10^{-4}	joule cm^{-2}
		0.09290	joule ft^{-2}
		6.452×10^{-4}	joule in.$^{-2}$
		10^{3}	erg cm^{-2}
		2.391×10^{-5}	cal cm^{-2}
		0.06852	ft lb ft^{-2}
		8.808×10^{-5}	Btu ft^{-2}
	watt hr m^{-2}	3600	watt sec m^{-2}
	watt hr ft^{-2}	3.875×10^{4}	
	kw hr m^{-2}	3.600×10^{6}	
	kw hr ft^{-2}	3.875×10^{7}	
	joule m^{-2}	1	
	joule cm^{-2}	10^{4}	
	joule ft^{-2}	10.764	
	joule in.$^{-2}$	1550	
	erg cm^{-2}	10^{-3}	
	cal cm^{-2}	4.182×10^{4}	
	ft lb ft^{-2}	14.60	
	Btu ft^{-2}	1.135×10^{4}	
Radiant helios, H_r (radiant brightness)	herschel	$1/\pi$	watt ster^{-1} m^{-2}
		$1/10^{4}\pi$	watt ster^{-1} cm^{-2}
		$1/10^{6}\pi$	watt ster^{-1} mm^{-2}
		0.02957	watt ster^{-1} ft^{-2}
		2.054×10^{-4}	watt ster^{-1} in.$^{-2}$
		$10^{3}/\pi$	erg sec^{-1} ster^{-1} cm^{-2}
		7.611×10^{-6}	cal sec^{-1} ster^{-1} cm^{-2}
		4.567×10^{-4}	cal min^{-1} ster^{-1} cm^{-2}
	watt ster^{-1} m^{-2}	π	herschel
	watt ster^{-1} cm^{-2}	$10^{4}\pi$	
	watt ster^{-1} mm^{-2}	$10^{6}\pi$	
	watt ster^{-1} ft^{-2}	33.82	
	watt ster^{-1} in.$^{-2}$	4869	
	erg sec^{-1} ster^{-1} cm^{-2}	$1/10^{3}\pi$	
	cal sec^{-1} ster^{-1} cm^{-2}	1.314×10^{5}	
	cal min^{-1} ster^{-1} cm^{-2}	2190	
Radiant heliosent, G_r (radiant brightness gradient)	herschel m^{-1}	$1/\pi$	watt ster^{-1} m^{-3}
		$1/10^{6}\pi$	watt ster^{-1} cm^{-3}
		$1/10^{9}\pi$	watt ster^{-1} mm^{-3}
		9.013×10^{-3}	watt ster^{-1} ft^{-3}
		5.216×10^{-6}	watt ster^{-1} in.$^{-3}$
		$10/\pi$	erg sec^{-1} ster^{-1} cm^{-3}
		7.611×10^{-8}	cal sec^{-1} ster^{-1} cm^{-3}
		4.567×10^{-6}	cal min^{-1} ster^{-1} cm^{-3}
	watt ster^{-1} m^{-3}	π	herschel m^{-1}
	watt ster^{-1} cm^{-3}	$10^{6}\pi$	
	watt ster^{-1} mm^{-3}	$10^{9}\pi$	
	watt ster^{-1} ft^{-3}	110.9	
	watt ster^{-1} in.$^{-3}$	1.917×10^{5}	
	erg sec^{-1} ster^{-1} cm^{-3}	$\pi/10$	
	cal sec^{-1} ster^{-1} cm^{-3}	1.314×10^{7}	
	cal min^{-1} ster^{-1} cm^{-3}	2.190×10^{5}	
Phenosage, $J(\lambda)$ (spectral flux density)	watt m^{-2} μ^{-1}	10^{-3}	kw m^{-2} μ^{-1}
		10^{-4}	watt cm^{-2} μ^{-1}
		10^{3}	erg sec^{-1} cm^{-2} μ^{-1}
		2.391×10^{-5}	cal sec^{-1} cm^{-2} μ^{-1}
		1.435×10^{-3}	cal min^{-1} cm^{-2} μ^{-1}
		8.808×10^{-5}	Btu sec^{-1} ft^{-2} μ^{-1}
		5.284×10^{-3}	Btu min^{-1} ft^{-2} μ^{-1}
		0.3171	Btu hr^{-1} ft^{-2} μ^{-1}
	kw m^{-2} μ^{-1}	10^{3}	watt m^{-2} μ^{-1}
	watt cm^{-2} μ^{-1}	10^{4}	
	erg sec^{-1} cm^{-2} μ^{-1}	10^{-3}	
	cal sec^{-1} cm^{-2} μ^{-1}	4.182×10^{4}	
	cal min^{-1} cm^{-2} μ^{-1}	697.0	
	Btu sec^{-1} ft^{-2} μ^{-1}	1.135×10^{4}	
	Btu min^{-1} ft^{-2} μ^{-1}	189.2	
	Btu hr^{-1} ft^{-2} μ^{-1}	3.154	

Luminous pharos, F_l	lumen (new, 1940)	1/647.8	young
		0.980	lumen (old)
	lumen (old)	1/634.8	young
		1.020	lumen (new)
	young	647.8	lumen (new)
		634.8	lumen (old)
Luminous pharosage, D_l (illumination)	lumen m^{-2}	1	lux
		1	m-candle
		10^{-4}	phot
		1/10.764	lumen ft^{-2}
		1/10.764	ft-candle
	lux	1	lumen m^{-2}
	m-candle	1	
	phot	10^{4}	
	lumen ft^{-2}	10.764	
	ft-candle	10.764	
Luminous phos, Q_l (quantity of light)	lumen sec (new, 1940)	1/60	lumen min
		1/3600	lumen hr
		1/647.8	young sec
	lumen min	60	lumen sec (new)
	lumen hr	3600	
	young sec	647.8	
Luminous phosage, U_l (quantity of light per unit area)	lumen sec m^{-2}	10^{-4}	lumen sec cm^{-2}
		0.09290	lumen sec ft^{-2}
		2.581×10^{-5}	lumen hr ft^{-2}
		1/647.8	young sec m^{-2}
	lumen sec cm^{-2}	10^{4}	lumen sec m^{-2}
	lumen sec ft^{-2}	10.764	
	lumen hr ft^{-2}	3.875×10^{4}	
	young sec m^{-2}	647.8	
Luminous intensity, I	candle (new, 1940)	0.98	candle (old)
	candle (old)	1.020	candle (new)
Luminous helios, H_l (brightness)	blondel	10^{-4}	lambert
		10^{-1}	millilambert
		0.09290	ft-lambert
		1	equiv. m-candle
		0.09290	equiv. ft-candle
		1	apostilb
		$1/10^{4}\pi$	stilb
		$1/\pi$	candle m^{-2}
		$1/10^{4}\pi$	candle cm^{-2}
		$1/10^{6}\pi$	candle mm^{-2}
		0.02957	candle ft^{-2}
		2.054×10^{-4}	candle in.$^{-2}$
	lambert	10^{4}	blondel
	millilambert	10	
	ft-lambert	10.764	
	equiv. m-candle	1	
	equiv. ft-candle	10.764	
	apostilb	1	
	stilb	$10^{4}\pi$	
	candle m^{-2}	π	
	candle cm^{-2}	$10^{4}\pi$	
	candle mm^{-2}	$10^{6}\pi$	
	candle ft^{-2}	33.82	
	candle in.$^{-2}$	4869	
Luminous heliosent, G_l (brightness gradient)	blondel m^{-1}	10^{-6}	lambert cm^{-1}
		10^{-3}	millilambert cm^{-1}
		0.02832	ft-lambert ft^{-1}
		1	equiv. m-candle m^{-1}
		0.02832	equiv. ft-candle ft^{-1}
		1	apostilb m^{-1}
		0.01	apostilb cm^{-1}
		$1/10^{6}\pi$	stilb cm^{-1}
		$1/\pi$	candle m^{-3}

Luminous heliosent, G_l (brightness gradient)—*Cont.*		$1/10^6\pi$	candle cm^{-3}
		$1/10^9\pi$	candle mm^{-3}
		9.013×10^{-3}	candle ft^{-3}
		5.216×10^{-6}	candle in^{-3}
	lambert cm^{-1}	10^6	blondel m^{-1}
	millilambert cm^{-1}	10^3	
	ft-lambert ft^{-1}	35.31	
	equiv. m-candle m^{-1}	1	
	equiv. ft-candle ft^{-1}	35.31	
	apostilb m^{-1}	1	
	apostilb cm^{-1}	100	
	stilb cm^{-1}	$10^6\pi$	
	candle m^{-3}	π	
	candle cm^{-3}	$10^6\pi$	
	candle mm^{-3}	$10^9\pi$	
	candle ft^{-3}	110.9	
	candle in.$^{-3}$	1.917×10^5	

by some physicists, but in the end it results in a more useful and more universal system of units.

Radiation and Photometry

In Table I(d), radiant power P is selected as fundamental, and all the other radiometric quantities are related in a simple geometric or temporal manner. If the radiometric quantities are weighted with respect to the standard lamprosity function for the human eye, one obtains the related *photometric concepts*. Corresponding to the *watt* is the *lumen*; corresponding to the *watt per square meter* is the *lumen per square meter*.

The names for the radiometric and photometric concepts of Table I(d) are not standard names but are those proposed to indicate the close correlation between the two sets of concepts.[8] Connecting these two sets are the *spectral lamprosity* and the *total lamprosity*, expressed in lumens per watt. Also sometimes used is *actance*, or luminous efficacy, of a source.

Closely related to the photometric concepts are the colorimetric concepts. Here, instead of a single weighting function (the standard lamprosity function), there are three. These are the CIE standard trichromatic functions[9] $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$. Weighting the radiant power density with respect to these three functions gives the trichromatic coordinates X, Y, Z.

One System or Several?

That the mks system should be treated in every textbook of general physics can hardly be questioned. Throughout the world, electric energy is sold by the *kilowatt hour*, potential difference is measured in *volts* and current in *amperes*. Other mks units are employed by all electrical engineers and many physicists. In other branches of science, however, conditions are different. Vestiges of other systems remain in use.

In writing a scientific book or paper, then, should the author conform to present usage or should he employ a single system of units throughout? There is room for a great deal of argument here. The view is sometimes stated that a textbook should not use any one set of units but the student should be encouraged to employ whatever set is most convenient for the problem in hand.[10] This attitude seems to overlook the very important question of *quantitative* thinking, which can hardly be done without some sort of *familiar* units. There is an immense pedagogic advantage in concentrating on a single set of units, which become eventually as familiar as one's own name. Thinking and calculating are always done in the familiar system, after which the results can be translated into any units that may be required.

It seems evident, therefore, that a textbook should concentrate on a single set of units throughout, with a chapter (if necessary) on con-

[8] P. Moon and D. E. Spencer, "A proposed international photometric system," *Am. J. Physics* **14**, 431 (1946); "A study of photometric nomenclature," *J. Opt. Soc. Am.* **36**, 666 (1946); "Photometric nomenclature for the post-war world," *Illum. Eng.* **42**, 611 (1947); *An unofficial guide to photometric nomenclature* (to be published).

[9] *Commission internationale de l'éclairage, 1931 session* (Cambridge Univ. Press, 1932), p. 25; P. Moon and D. E. Spencer, "Analytical representation of trichromatic data," *J. Opt. Soc. Am.* **35**, 399 (1945); "Analytic expressions in photometry and colorimetry," *J. Math. Physics* **25**, 111 (1946).

[10] W. H. Hall, "The formation of systems of units," *J. Franklin Inst.* **225**, 197 (1938).

version of units. The only comprehensive system that applies to all of physics and technology and that is international is the mks system. Therefore, use the mks system.[11]

To those of us who have been conditioned since childhood to think in the British system and whose scientific work has been principally in the cgs system, the mks units seem unpleasantly foreign. But to recondition ourselves to the new system should not be very difficult. Perhaps Table II will help.

Tables

One of the difficulties in writing a textbook that employs the mks system consistently throughout is the lack of available tables expressed in mks units. In an attempt to remedy this difficulty, we have provided a number of tables such as might be included in a physics textbook or handbook.

Table III lists some of the most important constants, values being obtained principally from Birge's publication[12] of 1942. Elastic moduli are listed in Table IV. Densities, specific heats and thermal conductivities are given in Table V, and some additional thermal data appear in Table VI. Electric and magnetic properties of materials are listed in Tables VII to IX. Table X gives conversion factors between the mks units and other units employed in physics and engineering.

Summary

The mks system gives a single comprehensive and international set of units for all of physics and engineering. It thus has both technological and pedagogic advantages over present usage. It has been employed extensively in recent textbooks, but authors seem to feel the lack of a general treatment of the mks system and a dearth of data expressed in mks units. The present paper attempts to remedy this difficulty by outlining the use of mks units in physics, and by giving tables of constants and conversion factors.

[11] Other treatments of the mks system are: G. E. M. Jauncey and A. S. Langsdorf, *Mks units and dimensions* (Macmillan, 1940); AAPT Committee on Electric and Magnetic Units, "What is the meter-kilogram-second system of units?" *Am. J. Physics* **6**, 144 (1938); W. H. Michener, "A brief table of meter-kilogram-second units," *Am. J. Physics* **8**, 318 (1940); A. E. Kennelly, "An international system of physical units and the teaching of such units to American students," *Am. J. Physics* **1**, 74 (1933); S. Gerszonowicz, *Unidades eléctricas y fotométricas* (Montevideo, 1941); G. Giorgi, "La métrologie électrique nouvelle et la construction du système électrotechnique absolu m.k.s.," *Rev. Gen. d'Elec.* **42**, 99 (1937).

[12] R. T. Birge, "The general physical constants," *Reports on Progress in Physics* **8**, 90 (1942); "The 1944 values of certain atomic constants with particular reference to the electronic charge," *Am. J. Physics* **13**, 63 (1945).

The rapid progress true Science now makes occasions my regretting sometimes that I was born so soon. It is impossible to imagine the height to which may be carried, in a thousand years, the power of man over matter. We may perhaps learn to deprive large masses of their gravity, and give them absolute levity, for the sake of easy transport. Agriculture may diminish its labor and double its produce; and all diseases may by sure means be prevented or cured, not excepting even that of old age, and our lives lengthened at pleasure beyond even the antediluvian standard. O that moral Science were in as fair a way of improvement, that men would cease to be wolves to one another, and that human beings would at length learn what they now improperly call humanity.
—Benjamin Franklin, in a letter to Joseph Priestley.

A Survey of Enrolments in College Science Courses

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THIS survey summarized herein was sponsored by Kewaunee Manufacturing Company in the endeavor to find a helpful answer to inquiries that had been received by it from representatives of colleges of liberal arts and sciences. Information regarding probable enrolments in various science courses in relation to total institutional enrolments was being sought by institutions planning development programs for the postwar period. The availability of such information should simplify the problem of determining the sizes of the laboratory rooms required to provide adequately for the work in the various college science courses.

Over a period of years Kewaunee had accumulated valuable information on room sizes desirable for various class sizes in laboratory courses, and on efficient laboratory layouts. However, no information regarding the relation of enrolments in science courses and the total college enrolments was available.

In the endeavor to secure the desired information, representative institutions were invited to provide enrolment figures. The colleges and universities selected for the survey—181 in all—were nearly all members of their respective Regional Accrediting Associations; most of them were also on the approved lists of the Association of American Universities and the American Association of University Women. Forty-seven states and the District of Columbia are represented; only Delaware is not included. Many of the colleges had already acquired the laboratory installation necessary for the efficient conduct of the science courses generally offered in American colleges.

The list of institutions follows:

Alabama
Albion
Allegheny
Alma
Amherst
Arizona State
Arizona U.
Augustana (Ill.)
Augustana (S.D.)
Baker
Baldwin Wallace
Bates
Baylor
Beloit
Bennington
Berea
Bethany
Birmingham-Southern
Blue Mountain
Bowdoin
Buffalo
Brigham Young
Bryn Mawr
Capital
Carleton
Carroll (Mont.)
Carroll (Wis.)
Centenary
Centre
Charleston
Chattanooga
City College (N. Y.)
Colby
Colgate
Colorado
Colorado Univ.
Concordia
Connecticut
Converse
Cornell
Cornell Univ.
Dartmouth
Davidson
Denison
De Paul
Dickinson
Doane
Drury
Dubuque
Earlham
Elmira
Emory
Franklin
Franklin and Marshall
Florida Southern
Florida State College
Furman
George Washington
Goucher
Grinnell
Grove City
Hamilton
Hamline
Hanover
Hardin-Simmons
Hastings
Haverford
Heidelberg
Hendrix
Hiram
Hood
Hope
Howard
Idaho
Illinois
James Millikin
Jamestown
John B. Stetson
Judson
Kalamazoo
Knox
Lafayette
Lake Erie
Lawrence
Lenoir Rhyne
Lewis and Clark
Linfield
Loyola
Macalaster
MacMurray
Manchester
Marshall
Mary Baldwin
Marygrove
Maryville
Meredith
Miami
Middlebury
Mills
Millsaps
Monmouth
Mount Holyoke
Mount St. Mary's
Mount Union
New Jersey Coll. for Women
New Mexico
Nevada
North Dakota
North Dakota Agricultural
Notre Dame (Md.)
Oberlin
Occidental
Ohio Univ.
Ohio Wesleyan
Oklahoma Coll. for Women
Oregon
College of Pacific
Park
Parsons
Phillips
Pomona
Princeton
Providence
Puget Sound
Randolph Macon
Redlands
Reed
Ripon
Rosary
St. Catherine
Saint Elizabeth
St. Lawrence
Saint Louis
St. Olaf
Saint Teresa
Scripps
Seton Hill
Simmons
Sophie Newcomb
Univ. of South
Southern Methodist
Southwestern
Sweet Briar
Swarthmore
Tarkio
Tennessee
Texas Christian
Transylvania
Trinity (Conn.)
Trinity (D.C.)
Tusculum
Union (Nebr.)
Union (N.Y.)
Vanderbilt
Vassar
Vermont
Wabash
Washburn Municipal
Washington
Washington and Lee
Washington State
Wayne
Wellesley
Wells
Western
Western Maryland
West Virginia
Wheaton
Whitman
Whittier
Wichita
Willamette
William and Mary
Williams
Wilson
Winthrop
Wittenberg
Woman's Coll., Univ. of N.C.
Wooster
Wyoming
Yankton

The 181 institutions were arranged in four groups on the basis of total student enrolments, as follows:

(1) 49 colleges with enrolments of less than 500 (26 coeducational; 4 men's; 19 women's);

(2) 38 colleges with enrolments of 500 to 750 (27 coeducational; 3 men's; 8 women's);

* Now at University of Florida.

TABLE I. Physics (percentages).

Subject	Coeducational 1940–41 All	Coeducational 1940–41 Upper Third	Coeducational 1945–46 All	Coeducational 1945–46 Upper Third	Men 1940–41 All	Men 1940–41 Upper Third	Men 1945–46 All	Men 1945–46 Upper Third	Women 1940–41 All	Women 1940–41 Upper Third	Women 1945–46 All	Women 1945–46 Upper Third
(a) Institutions with less than 500 students each												
General physics	9.4	16.3	8.5	15.0	10.9	11.9	13.0	18.2	4.7	8.5	7.0	12.2
Adv. mechanics	0.3	1.9	1.1	1.9	1.3	1.8	2.1	2.1	1.6	1.6	1.5	1.7
Adv. heat	1.7	2.7	1.3	1.8	—	—	0.4	0.4	1.7	1.7	1.0	1.0
Adv. light	1.3	1.9	1.5	2.2	1.1	1.1	0.8	0.8	1.1	1.4	2.1	2.5
Adv. electricity & magnetism	1.9	3.1	1.3	2.1	1.2	1.7	1.6	1.6	1.6	1.6	1.1	1.5
Radio waves & vacuum tubes (electronics)	2.5	3.8	1.6	2.5	1.9	2.1	1.0	1.3	0.8	0.8	1.0	1.0
Modern physics	1.2	2.1	1.7	2.6	—	—	2.5	3.8	0.9	0.9	1.0	1.0
Total students			8665			1412					6677	
(b) Institutions with 500–750 students each												
General physics	7.6	12.4	9.2	17.4	8.3	12.7	15.7	28.0	3.4	7.7	3.6	6.2
Adv. mechanics	1.9	3.5	1.6	2.8	3.2	4.4	1.6	1.7	0.9	1.3	1.2	1.5
Adv. heat	1.4	2.7	1.0	1.5	—	—	1.4	1.6	0.5	0.7	0.7	0.7
Adv. light	1.4	2.3	1.4	2.5	5.1	5.1	0.5	0.5	1.1	1.5	0.5	0.5
Adv. electricity & magnetism	1.7	2.9	1.3	2.6	1.4	1.4	1.6	1.6	0.5	0.5	1.3	5.6
Radio waves & vacuum tubes (electronics)	1.0	1.4	1.8	3.5	6.7	6.7	1.1	1.1	1.0	1.0	1.0	8.0
Modern physics	1.1	1.4	1.2	1.8	4.4	4.4	—	—	—	—	1.1	1.1
Total students			18 044			1182					4637	
(c) Institutions with 751–999 students each												
General physics	8.1	14.4	10.9	25.7	11.2	17.5	4.8	4.8	5.6	7.7	4.2	5.2
Adv. mechanics	1.3	2.4	1.4	2.7	0.9	1.3	—	—	0.2	0.2	0.8	0.8
Adv. heat	1.9	5.6	2.5	4.9	3.3	6.1	—	—	—	—	0.6	0.6
Adv. light	0.9	1.4	1.0	1.4	3.3	6.1	—	—	—	—	—	—
Adv. electricity & magnetism	1.2	2.1	0.8	1.8	1.3	2.0	—	—	0.2	0.2	—	—
Radio waves & vacuum tubes (electronics)	1.0	1.2	1.3	2.2	1.3	2.5	—	—	—	—	—	—
Modern physics	0.7	1.0	0.6	0.9	—	—	—	—	—	—	—	—
Total students			19 694			4257					2302	
(d) Institutions with 1000 or more students each												
General physics	9.0	21.7	8.9	20.4	13.4	16.8	10.9	14.0	3.6	6.0	5.4	9.8
Adv. mechanics	0.8	1.9	0.6	1.9	1.3	3.0	1.8	3.5	0.3	0.3	0.4	0.9
Adv. heat	0.2	0.5	0.7	1.9	0.9	0.9	0.4	0.9	0.5	0.6	0.2	0.3
Adv. light	0.2	0.7	0.5	2.6	0.6	0.6	0.6	0.8	0.6	0.7	0.4	1.0
Adv. electricity & magnetism	0.5	1.4	0.4	1.0	1.3	1.7	1.8	3.2	0.4	1.1	1.5	4.0
Radio waves & vacuum tubes (electronics)	0.4	1.0	0.3	9.0	0.4	0.4	0.2	0.6	0.4	1.1	0.7	1.2
Modern physics	0.2	0.9	0.2	0.9	1.5	2.0	0.4	0.6	0.3	0.3	1.0	2.0
Total students			128 902			9144					12 478	

(3) 34 colleges with enrolments of 751 to 999 (24 coeducational; 6 men's; 4 women's);

(4) 60 colleges with enrolments of 1000 or more (46 coeducational; 5 men's; 9 women's).

The total enrolment figures and class enrolments in science were secured for the college years 1940–41 and 1945–46. The year 1940–41 was selected because it was considered to be the last college year preceding the war during which enrolments were not affected appreciably by war conditions.

The science courses included in the survey were as follows:

Physics: general physics, advanced mechanics, advanced heat, advanced light, advanced electricity and magnetism, radio waves and vacuum tubes (or electronics), modern physics.

Chemistry: general chemistry (including qualitative analysis when given as part of the first year's work), advanced qualitative analysis, quantitative analysis, organic chemistry, physical chemistry.

Biology: first course in general biology, botany or zoology, advanced botany, advanced zoology, vertebrate embryology, vertebrate anatomy, general bacteriology.

Miscellaneous: a group including general geology, paleontology, home economics (for foods only), experimental psychology.

TABLE II. Chemistry (percentages).

	Coeducational				Men				Women			
	1940–41		1945–46		1940–41		1945–46		1940–41		1945–46	
Subject	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third
(a) Institutions with less than 500 students each												
Gen. chem.	15.9	20.9	15.7	25.6	12.2	19.1	13.1	22.8	13.3	19.2	14.2	23.0
Qual. chem.	3.5	7.3	2.6	5.2	4.6	9.0	3.1	4.0	2.4	5.0	3.4	6.5
Quant. chem.	3.9	6.7	2.5	4.6	5.0	6.2	2.3	4.1	2.9	5.6	3.2	5.0
Organic chem.	5.4	10.5	3.1	5.6	5.0	7.6	3.2	10.8	4.9	8.5	3.1	4.2
Phys. chem.	1.9	3.5	1.2	2.0	2.5	4.4	1.9	3.2	1.1	2.5	1.2	1.5
Total students		8665				1412				6677		
(b) Institutions with 500–750 students each												
Gen. chem.	11.3	17.7	14.8	23.7	13.8	15.8	16.7	22.3	14.6	19.2	12.2	17.9
Qual. chem.	4.5	7.0	2.5	4.0	5.6	8.6	2.7	4.3	1.4	2.3	1.8	2.9
Quant. chem.	3.4	5.3	2.1	3.5	3.1	6.7	2.8	4.5	2.0	3.0	1.3	1.9
Organic chem.	3.4	5.1	2.8	4.6	5.9	8.5	6.0	12.3	4.0	9.0	4.7	9.3
Phys. chem.	1.4	2.5	0.9	1.4	3.8	7.2	1.6	2.4	1.9	2.2	2.1	3.2
Total students		18 044				1182				4637		
(c) Institutions with 751–999 students each												
Gen. chem.	14.6	22.1	13.3	21.9	12.9	20.1	15.7	24.5	12.2	14.8	10.2	10.3
Qual. chem.	3.2	5.2	2.9	5.2	6.0	7.6	1.0	1.4	1.1	1.3	1.9	2.9
Quant. chem.	2.4	3.3	2.0	3.4	3.5	6.4	2.1	2.6	1.0	1.3	2.4	2.9
Organic chem.	3.9	6.1	2.4	4.6	3.9	7.5	1.9	2.5	4.0	6.2	1.3	2.7
Phys. chem.	1.4	2.5	1.1	2.3	2.3	4.7	—	—	0.5	0.7	1.1	1.7
Total students		19 694				4257				2302		
(d) Institutions with 1000 or more students each												
Gen. chem.	11.3	21.2	12.9	25.1	15.7	21.0	18.3	31.1	12.8	17.0	14.5	17.8
Qual. chem.	2.1	3.7	1.3	2.8	4.1	5.5	1.3	1.7	1.1	2.3	1.5	2.6
Quant. chem.	2.2	4.8	1.5	2.7	3.7	4.7	1.3	2.0	2.7	4.9	3.6	6.5
Organic chem.	4.2	7.1	2.3	3.8	8.7	13.0	5.4	7.8	6.5	14.4	5.0	9.6
Phys. chem.	1.3	2.8	0.7	1.4	2.6	3.6	1.8	5.8	1.0	1.8	2.5	4.8
Total students		128 902				9144				12 478		

The results of the survey are presented in Tables I to IV, in the form of percentages. The percentages given in the columns headed "all" were determined for each course listed by dividing the total combined student enrolments in such a course by the combined institutional enrolments of those institutions reporting enrolments in that particular course.

The percentages for the third of the colleges having the largest relative enrolments in each of the subjects are also given for each year, in the column headed "upper third."

Since some of the percentages were small, as anticipated, the computations were carried out uniformly to the nearest 0.1 percent.

Blank spaces in the tables for any particular group of colleges indicate that there were no enrolments reported for these courses by the institutions of that group.

The percentages computed for home economics in coeducational institutions were based upon the enrolment of women only.

In many institutions, particularly in those with enrolments less than 750, several advanced courses are offered in alternate years only. Using the data on enrolment for two college years had the effect of approximating closely the enrolment figures when the courses are offered.

Particular conditions in a few institutions resulted in abnormal enrolments in some courses; however, it was deemed wise to incorporate all of the enrolment figures as submitted in computing the tabulated results.

TABLE III. Biology (percentages).

Subject	Coeducational 1940–41 All	Upper Third	1945–46 All	Upper Third	Men 1940–41 All	Upper Third	1945–46 All	Upper Third	Women 1940–41 All	Upper Third	1945–46 All	Upper Third
(a) Institutions with less than 500 students each												
Gen. biology	24.2	40.0	21.6	31.5	14.5	17.0	23.5	31.6	20.3	30.6	17.1	21.9
Adv. botany	4.9	9.0	3.2	7.0	—	—	6.5	9.7	2.8	5.0	2.3	5.4
Adv. zoology	7.1	14.6	4.0	9.6	13.4	13.4	1.8	2.0	2.5	3.9	3.1	4.2
Vert. embryology	4.3	5.8	2.5	5.9	5.1	6.2	4.7	7.2	2.2	2.7	1.9	3.2
Vert. anatomy	4.8	7.5	3.2	4.5	4.8	6.4	4.0	7.2	2.6	3.9	3.6	5.3
Bacteriology	4.1	6.9	3.3	5.5	1.1	1.4	—	—	5.6	6.9	2.7	4.2
Total students	8665				1412				6677			
(b) Institutions with 500–750 students each												
Gen. biology	19.1	31.1	21.4	36.3	11.5	13.6	8.1	11.9	18.3	25.1	16.7	22.4
Adv. botany	6.5	15.3	4.5	7.9	—	—	—	—	6.1	10.0	3.5	6.1
Adv. zoology	5.2	10.0	2.7	5.6	5.2	7.5	2.1	2.8	4.6	7.8	4.1	7.3
Vert. embryology	2.2	3.6	1.6	2.9	1.2	1.2	2.4	2.4	1.3	2.3	1.3	1.7
Vert. anatomy	3.2	5.9	2.3	4.1	2.6	2.6	2.1	2.1	7.0	14.5	3.9	6.0
Bacteriology	2.5	4.0	2.3	3.7	2.3	3.5	—	—	4.0	8.0	3.7	6.6
Total students	18 044				1182				4637			
(c) Institutions with 751–999 students each												
Gen. biology	17.9	23.7	15.0	20.6	11.2	11.5	13.2	13.9	26.5	31.2	19.7	23.0
Adv. botany	1.9	3.0	1.9	3.1	2.4	4.1	—	—	1.3	1.9	1.0	1.5
Adv. zoology	5.2	10.0	3.1	6.4	1.7	2.6	0.5	0.6	2.5	4.2	2.0	3.2
Vert. embryology	1.9	2.8	1.0	1.6	3.3	4.3	0.4	0.4	1.6	2.2	1.5	1.5
Vert. anatomy	2.9	4.6	1.8	2.7	3.6	5.7	0.7	1.8	2.0	2.2	2.3	3.0
Bacteriology	2.4	4.0	1.6	2.7	1.6	2.1	1.0	1.0	4.0	5.1	2.6	3.6
Total students	19 694				4257				2302			
(d) Institutions with 1000 or more students each												
Gen. biology	10.9	21.6	11.0	27.6	12.1	16.6	7.8	13.0	19.3	27.3	19.0	35.3
Adv. botany	1.2	2.7	0.7	1.3	1.6	1.6	0.9	0.9	3.3	4.8	2.5	4.2
Adv. zoology	2.6	7.9	2.4	5.1	2.6	5.2	0.7	1.4	2.5	4.6	1.9	2.9
Vert. embryology	0.8	2.0	0.7	2.1	3.0	4.3	1.6	4.8	1.1	2.4	0.9	2.6
Vert. anatomy	1.2	2.7	1.1	2.9	3.2	4.6	3.2	8.0	2.8	4.6	3.1	8.3
Bacteriology	2.1	6.5	1.4	2.7	0.6	1.0	—	—	4.6	6.6	4.9	8.9
Total students	128 902				9144				12 478			

A careful inspection of the tabulated results indicates, in the opinion of the writer, that use of the findings may yield a fair estimate of the student enrolment in a science course for which accommodations should be planned in the expansion program of an institution.

Suggested Use of Tabulated Data

The fact is recognized that the development of the science offerings in American colleges may be affected by the location and by the goals adopted for emphasis in the institutional program. No common percentage could be chosen arbitrarily for use in determining the anticipated enrolment in any college course in science. However, in a significant number of cases, as revealed in the tabulations, the close agreement of results for the two years studied indicates that the average percentage for the two years for the "upper third" may be used helpfully for securing a close approximation to probable enrolment figures for projected institutional programs. It is further suggested that even in the cases in which the "upper third" percentages for the two years differ appreciably, the use of the average percentage would yield at least a rough approximation to actual enrolment figures.

Our warm appreciation is hereby expressed to the institutional representatives who generously supplied the enrolment figures on which the present study was based. The author will welcome comments from readers.

TABLE IV. Geology, paleontology, home economics, experimental psychology (percentages).

	Coeducational				Men				Women			
	1940–41		1945–46		1940–41		1945–46		1940–41		1945–46	
Subject	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third	All	Upper Third
(a) Institutions with less than 500 students each												
Geology	6.0	9.5	5.5	10.0	15.9	15.9	6.9	6.9	2.6	2.6	—	—
Paleontology	2.5	3.0	1.9	1.9	0.5	0.5	—	—	—	—	—	—
Home economics	8.6	12.2	7.5	12.6	—	—	—	—	18.7	27.9	12.1	19.5
Exp. psychology	4.7	9.9	6.2	15.7	14.9	20.6	25.1	25.1	6.5	11.7	2.5	3.9
Total students	8665				1412				6677			
(b) Institutions with 500–750 students each												
Geology	7.6	12.1	7.2	14.6	5.3	13.9	1.6	2.4	6.6	9.9	6.9	9.9
Paleontology	1.9	3.6	1.4	1.6	11.1	11.1	—	—	3.6	3.6	4.3	6.9
Home economics	9.7	21.9	9.7	12.8	—	—	—	—	8.5	15.7	7.6	13.7
Exp. psychology	3.5	9.4	5.9	16.1	2.5	3.2	—	—	4.5	9.1	4.8	9.2
Total students	18 044				1182				4637			
(c) Institutions with 751–999 students each												
Geology	7.4	14.1	6.8	12.0	9.2	12.8	3.7	3.7	0.3	0.3	—	—
Paleontology	1.3	1.4	1.5	1.9	0.9	1.7	0.4	0.4	—	—	—	—
Home economics	14.1	22.5	7.7	10.3	—	—	—	—	17.0	23.6	5.1	5.1
Exp. psychology	2.9	7.4	2.9	6.7	3.0	4.6	1.4	1.4	3.3	6.7	7.0	11.6
Total students	19 694				4257				2302			
(d) Institutions with 1000 or more students each												
Geology	5.3	12.7	5.1	15.4	8.2	10.3	5.4	6.2	3.8	7.8	3.8	8.5
Paleontology	0.5	1.1	0.4	0.9	1.2	2.3	0.8	0.8	0.4	0.6	0.5	0.5
Home economics	9.8	11.5	9.7	19.9	—	—	—	—	13.8	18.9	19.9	31.3
Exp. psychology	0.7	2.3	0.7	1.7	1.0	1.5	1.9	2.3	10.8	21.8	4.3	6.2
Total students	128 902				9144				12 478			

Poetic License!

A magnet hung in a hardware shop,
And all around was a loving crop
Of scissors and needles, nails and knives,
Offering love for all their lives;
But for iron the magnet felt no whim,
Though he charmed iron, it charmed not him;
From needles and nails and knives he'd turn,
For he'd set his love on a silver churn!

And iron and steel expressed surprise,
The needles opened their well-drilled eyes,
The penknives felt "shut up," no doubt,
The scissors declared themselves "cut out,"
The kettles they boiled with rage, 'tis said,
While every nail went off its head,
And hither and thither began to roam,
Till a hammer came up—and drove them home.

W. S. GILBERT, *Patience*, Act II.

A Classroom Demonstration of Alpha-Particle Scintillations

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THE most direct method of observing individual alpha particles is to make use of a substance that has the property of becoming luminous under the action of such particles. There are several substances which, when bombarded with alpha particles, produce flashes of light or scintillations that can be observed under a low-power microscope. Each alpha particle gives rise to a flash of light which has a duration of about 100 μsec. Some of the compounds exhibiting this property are zinc silicate, barium platino-cyanide, scheelite, and zinc sulfide. These compounds must be prepared in a special way in order to produce these scintillations. The most satisfactory of these materials is zinc sulfide. Hevesy and Paneth[1] describe a method of preparing a screen coated with such material.

This principle is applied in the spinthariscope, which consists simply of a source of alpha particles, a zinc sulfide screen, and a magnifying glass for viewing the resulting scintillations. The use of a spinthariscope in a classroom demonstration is, however, impractical for several reasons: only one student can make observations at a time; considerable practice and instruction is necessary in order to make intelligent observations; and it is essential to work in a darkened room.

A rather satisfactory classroom demonstration can be arranged by using a spinthariscope in conjunction with a photomultiplier type of photoelectric cell. These photoelectric cells are extremely sensitive to weak light signals and are thus ideally suited for this type of demonstration. The circuit shown in Fig. 1 is designed as a general-purpose unit and therefore contains features that are not necessary in this demonstration.

The transformer is a radio-type transformer having a secondary voltage of 660 v on each side of the center tap. It is used in a circuit employing a type 2X2 half-wave rectifier. The full voltage of the secondary is impressed on the rectifier. The output voltage is controlled by means of a General Radio Variac in the primary circuit of the transformer. Filtering is accomplished by a choke-input filter consisting of a 30-h choke and a 4-μf condenser. Voltage is supplied for the various dynodes of the multiplier by a 100,000-ohm bleeder resistance, tapped at equal intervals. The last stage, dynode number 9 to anode, is made variable independently of the other stages by means of a 5,000-ohm, 50-w wire-wound potential divider. A 0–150-v voltmeter is connected in the circuit in such a way that it can be used to measure either the voltage per stage or the voltage impressed on the last stage (dynode number 9 to anode). A double-pole double-throw switch is used to switch the meter from one position to the other. A milliammeter (0–1 ma) is placed in the anode circuit, with binding posts provided for an external meter or oscilloscope. When an external indicator is used, the switch in the milliammeter circuit is opened.

To demonstrate the existence of the scintillations, the photomultiplier tube is mounted in a light-tight container. A spinthariscope is placed near the sensitive surface of the tube. An oscilloscope is connected to the output terminals. As the voltage is raised, sharp pulses are observed on the oscilloscope screen at voltages of about 75 to 100 v per stage. The magnitude of the pulses depends, of course, on the amplification of the oscilloscope. No additional amplification is required for oscilloscopes of fairly high gain. Inserting an opaque screen between the spinthariscope and the photomultiplier tube causes the large pulses to disappear, thus showing that the scintillations cause the pulses. Much smaller pulses due to the dark or background current are always present.

Since the energy per scintillation is a function of the energy of the incident alpha particle, it is evident that the size of the pulses will be related to the distance separating the source and the screen. This distance is not variable in the usual spinthariscope, and it is therefore necessary to

[1] Hevesy and Paneth, *A manual of radioactivity* (Oxford, ed. 2), pp. 242–6.

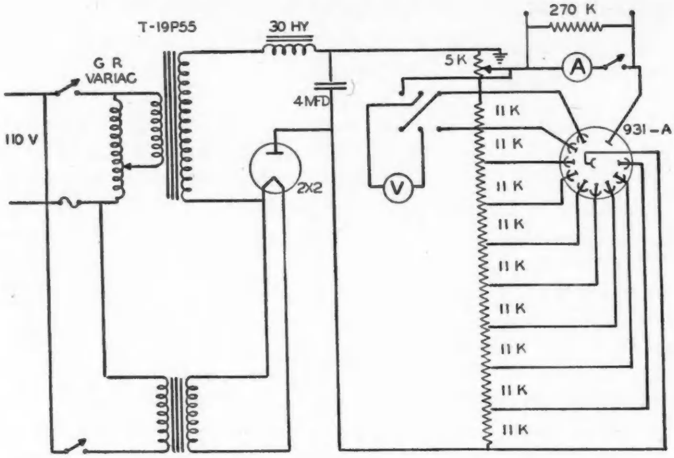

FIG. 1. Photomultiplier circuit and power supply.

use a slightly different arrangement to show this effect. A zinc sulfide screen is mounted directly in front of the photomultiplier tube, and the source of alpha particles is mounted in such a way that its distance from the screen can be varied. As the distance between the source and screen is increased, the size of the pulses gradually decreases. If the distance exceeds the range of the particles, it is obvious that there will be no pulses due to alpha particles. This may suggest an easy method of measuring range, but it has not seemed practical because the size of the pulses near the end of the range becomes small and they are no longer distinguishable from the electron pulses of the background or dark current. For this reason, range measurements made by this method usually yield values which are a few millimeters shorter than the accepted values.

Young men, have confidence in those powerful and safe methods, of which we do not yet know all the secrets. And, whatever your career may be, do not let yourselves become tainted by a deprecating and barren skepticism, do not let yourselves be discouraged by the sadness of certain hours which pass over nations. Live in the serene peace of laboratories and libraries. Say to yourselves first, "What have I done for my instruction?" and as you gradually advance, "What have I done for my country?" until the time comes when you may have the immense happiness of thinking that you have contributed in some way to the progress and to the good of humanity. But whether our efforts are, or not, favored by life, let us be able to say, when we come near the great goal, "I have done what I could."—LOUIS PASTEUR.

A Circuit for Continuously Tracing a Set of Tube Characteristics*

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At different times there have been suggestions for methods of plotting a tube's characteristic curves continuously on the screen of a cathode-ray oscilloscope.[1,2] In general, these devices plotted one curve of the family, and some mechanical control was moved to get the next member. It was thought desirable for both classroom and other demonstration work, as well as for tube check, comparison and study, to be able to display the whole family of curves at one time. The previous attempts to do this have usually resulted in a cumbersome mechanical switching arrangement which gave trouble by poor or erratic contact, sparking and so forth. Clearly, an electronic switch of some type would be desirable. It would have to supply a set of regularly increasing voltages, each at the right time and having the correct duration, and then repeat the sequence.

Consider, for example, the graph of plate current of a tube as a function of plate voltage. A family of curves results when different values of grid voltage, usually shown separated by about 1v, are used. A single member of the family could be obtained by placing a fixed voltage on the grid of the tube and applying a 350-v, 60-c/sec alternating potential to the plate in series with a resistor. The plate-cathode voltage could be applied to the horizontal deflection plates of an oscilloscope and the voltage drop across the resistor, being proportional to the plate current, to the vertical plates. As the plate of the tube under test starts to go positive, the characteristic curve is traced during the first quarter-cycle. It is then retraced backward to zero on the next quarter. The negative half-cycle yields merely a horizontal straight line off the screen, which can be eliminated by means of a diode. If the grid voltage is kept fixed, this curve is repeatedly retraced every other half-cycle.

After the curve has been traced in both directions on one-half of the 60-c/sec wave, it is desirable to change the potential of the grid by about 1v during the other half-cycle in preparation for a new trace at a new value of grid voltage on the succeeding cycle. To do this, a condenser (Fig. 1) is charged through a pentode during this off half-cycle by raising the pentode's two grid voltages above the cut-off values. The constants are so chosen that the voltage across the condenser increases by about 20v during one such period. A pentode, being a constant-current device, tends to bring about the same increase on each charging half-cycle. After, say, five increments, a thyratron across the condenser discharges it to start the process over.

The voltage across the 40,000-ohm cathode resistor of the 6J5 tube tends to stay very close to that across the condenser. Thus we have at our disposal a voltage that varies in steps, a fraction of it being suitable to give different biases to the tube under test. Since the condenser and the resistor have about the same potential drop across them, the condenser discharges through the resistor quite slowly (that is, a cathode coupled amplifier has a relatively high input impedance). It is necessary to have the voltages supplied by the two transformers 180° out of phase so that the condenser charges on the half-cycle when no trace is in progress, that is, when the plate voltage of the tube, after one member of the family of curves has been traced, is going negative and then returning to zero.

By having fairly large voltage increments on the condenser, and then using only a given fraction of this voltage, one minimizes irregularities in general, and, in particular, one makes the thyratron action regular and reliable. Use of the cathode follower makes this fraction easy to vary. By applying a suitable fixed bias to the tube under test, it is possible to attain the zero-bias curve even though the condenser never completely discharges.

The circuit diagram is shown with batteries supplying the several voltages for the sake of clarity of description, but these voltages could be obtained from the power supply. As the circuit stands, line-voltage variations will affect the average control voltages on the pentode, and hence will affect the resulting set of biases on the tube

* After the present paper had been accepted for publication, an article by H. E. Webking that describes a basically similar experiment appeared in the November 1947 issue of *Electronics*.

1 Street, *Electronics* 14, 5 (1941).

2 Millman and Moskowitz. *Electronics* 14. 36 (1941).

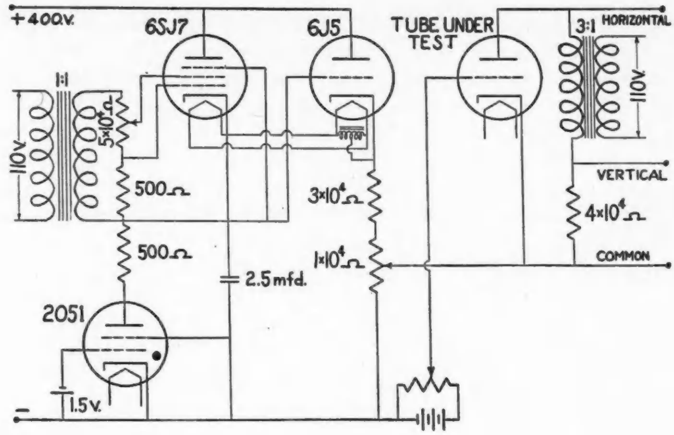

FIG. 1. Circuit used for plotting a family of tube characteristic curves on an oscilloscope screen. A triode is shown under test. A current-indicating resistor of 40,000 ohms is suitable for many low-current tubes, but should be reduced for power tubes, for example.

under test by varying the average condenser charging current and the resulting voltage increments. Line voltages change only by a small percentage, so the biases should be only a similarly small percentage different from their expected values. For precise quantitative measurements even this could be taken care of by regulating the input alternating voltage or by applying regulated direct voltages to the grids and plate of the pentode.

The usual amplifiers found in oscilloscopes do not have low enough phase shift and distortion to give good results. The circuit, as shown, is meant to be used directly coupled to the deflection plates. If this is not done, each curve will loop into a double trace. Similarly, any study of the step voltage across the condenser must employ direct coupling. If one wishes to deal with lower voltages, such as would be encountered in the study of transfer characteristics to be discussed presently, it is necessary to introduce amplifiers of quite high quality, since even small electrode capacitances can cause noticeable phase shift.[2] If, for a demonstration, one wishes to avoid the trouble of constructing a good amplifier, the offending return traces produced by a poor amplifier can be removed to make the curves look correct. This is accomplished by attaching an *RC* differentiating circuit across one of the applied a.c. voltages and then applying the differentiated voltage to the grid (*z* axis) of the cathode-ray tube, thus cutting off the beam for the half of each cycle during which the curve retraces itself and goes negative. We might note that an attempt to further simplify the circuit by replacing the cathode follower by a simple capacitance voltage divider would leave the grid of the tube under test too isolated for best operation. The main difficulty would arise at small values of bias, where even a grid leak with a long time constant might well prove inadequate.

Such an arrangement as here discussed has several possible uses. It can be used to give more information about a tube's condition than any usual tube tester. A given tube's characteristics can, for the usual purposes, be quickly obtained. This includes running the characteristic curves to the often momentarily encountered region beyond the steady-state recommendations, which process would be damaging if done by a static point-by-point method. In demonstrations it can clearly show such things as the differences between triodes, tetrodes and pentodes, possibly by using a single test tube and connecting its grids in different ways. The effect of the intro-

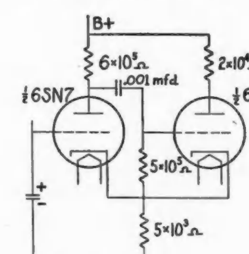

FIG. 2. An alternative method for discharging a condenser after it has been charged to a predetermined voltage. The condenser and voltage increments here employed would be relatively small.

duction of gas into a tube can be observed by studying the curves of a thyratron. A tube's properties can be easily examined. This includes the variation of parameters, the effect of which is not usually available. For example, the constant-current properties of a pentode or the negative-resistance properties of a tetrode as a function of screen voltage can be studied by merely watching the curves change as the potentiometer controlling the screen voltage on a test tube is varied. Circuit constants to produce a desired effect with a given tube can often be determined in an unusually simple manner.

Most of the other tube characteristics that one can think of can be similarly plotted. If the curves of plate current *versus* grid voltage are desired, the same type of switch may be used to control the voltage coming from a regulated power supply feeding the plate of the tube under study. The grid, biased beyond cut-off, is fed by the alternating voltage that also activates one pair of oscilloscope plates. The other pair of plates is controlled by a series resistor measuring the plate current. One set of curves difficult to obtain is the one showing the plate current of a diode *versus* plate voltage as the filament voltage is varied in steps. This family must be obtained one member at a time because of the large thermal inertia of the filament and consequent long time necessary for the attainment of an equilibrium temperature.

In all cases, the number of cycles before reset is determined by the pentode voltages—that is, the charging current—and the bias of the thyratron. The actual output voltage is determined by the condenser voltage and the fraction thereof taken off of the cathode resistor. In the circuit of Fig. 1, variation of the screen potentiometer will change the number of curves traced from three to six. The thyratron fires when the potential difference across the condenser is about 150v.

A modification of the circuit makes use of multivibrator action to discharge the condenser, thus dispensing with any gas-filled tube. Such a circuit (Fig. 2) can, unlike a thyratron, almost completely discharge a condenser and can be made to fire reliably at a lower voltage. The right-hand tube conducts enough current through the 5000-ohm resistor to cut off the left-hand tube until the condenser step voltage rises high enough. Then the left-hand tube starts conducting, thus lowering its own plate potential. This, by virtue of the coupling condenser, lowers the grid potential of the right-hand tube below cut-off, thus removing the bias current and bias. The grid of the left-hand tube, now being positive with respect to its cathode, draws current from the condenser, thus discharging it. The large resistor in the plate circuit of the left-hand tube prevents its own current from maintaining an appreciable bias voltage during this period. The negative bias is not returned until the charge on the coupling condenser leaks off through the grid resistor of the right-hand tube, whereupon the initial condition is resumed.

It is hoped that such a simple switching arrangement will find other uses besides those indicated. We might note that either of these two circuits would serve as an excellent frequency divider, though the second method of condenser discharge would serve this purpose best.

Perhaps the most valuable result of all education is the ability to make yourself do the thing you have to do, when it ought to be done, whether you like it or not; it is the first lesson that ought to be learned; and however early a man's training begins, it is probably the last lesson that he learns thoroughly.—THOMAS HENRY HUXLEY.

Teaching Aids in Alternating-Current Theory for the College Physics Course

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ALTERNATING currents are of such importance in industry that the inclusion of some of the simpler theory is mandatory in any substantial physics course. The student in an industrial center early learns that almost all the motors that are readily available are not those described in his science books. He hears discussions of power-factor correction and statements that up to 5-percent rebate is allowed by some local utilities for good power factor. Rumors have it that certain companies opposed the installation of the early fluorescent lighting in fear of loss of load. Actually, the opposition was not so much in fear of loss of load as of the extremely bad power factor (about 50 percent) of the early fixtures. No power company could afford to accept such a large lighting load without adequate advance preparation. Frequently questions are brought in by students who see what are actually substation or pole installations of static condensers. Such devices do not have the general appearance of transformers, so what are they? The answer is that if a small factory will not correct its power factor, the power company itself will frequently float capacitors across the line. Certainly such illustrations as the foregoing should make the college physics teacher more conscious of industrial alternating-current problems.

It has been pointed out that the author of a physics textbook is, in a sense, a "knowledge compressor." If authors do not sufficiently exercise their function as compressors, the student of the future can look forward to carrying many more pages to class and probably reading fewer of them than does his present-day brother. In what follows we give the results of a series of experiments on the compression of alternating-current theory. The necessity for these experiments arose from the experiences of one of us when he was assigned to teach certain courses in electrical engineering. The students in these courses were the product of the physics teacher's own department. After several semesters he was tempted to conclude that not only is knowledge compression desirable but a more perfect knowledge adhesive should be developed.

Alternating-current theory is not inherently difficult, but the arithmetic associated with the solutions of the problems frequently becomes a major obstacle. When a student becomes involved in arithmetic errors, he is likely to miss the beauties of the forest because he is enmeshed in a thicket of thorn bushes. The arithmetic difficulty seems to be located in handling reactances in further calculation. It has been found that if values of capacitance and inductance are so chosen that their corresponding

Table I. Inductances and capacitances to give more usable values of reactances at certain frequencies.

Inductance (h) to give specified reactance at given frequency			Reactance (ohms)	Capacitance (μf) to give specified reactance at given frequency		
1000 c/sec	440 c/sec	60 c/sec		60 c/sec	440 c/sec	1000 c/sec
0.001591(6)	0.003617	0.02653	10	265.3	36.17	15.91(6)
.003979	.009046	.06631	25	106.1	14.47	6.366
.007958	.01809	.13263	50	53.05	7.235	3.182
.009549	.02170	.1592	60	44.21	6.029	2.652(6)
.011937	.02713	.1989	75	35.37	4.823	2.122
.015916	.03617	.2653	100	26.52(6)	3.617	1.591(6)
.01910	.04341	.3183	120	22.10(5)	3.014	1.326
.02228	.05064	.3714	140	18.94(7)	2.584	1.137
.02387	.05426	.3979	150	17.68	2.411	1.061
.02546(5)	.05787(5)	.4244	160	16.57(9)	2.260(7)	0.9948
.03183	.07234	.5305	200	13.26(3)	1.1808(5)	.7958
.03979	.09043	.6631	250	10.61	1.447	.6366
.04774(7)	.10852	.7958	300	8.842	1.206	.5305
.07958	.1808(6)	1.3263	500	5.305	0.7235	.3183
.1591(6)	.3617	2.6525	1000	2.653(5)	.3617	.1591(6)

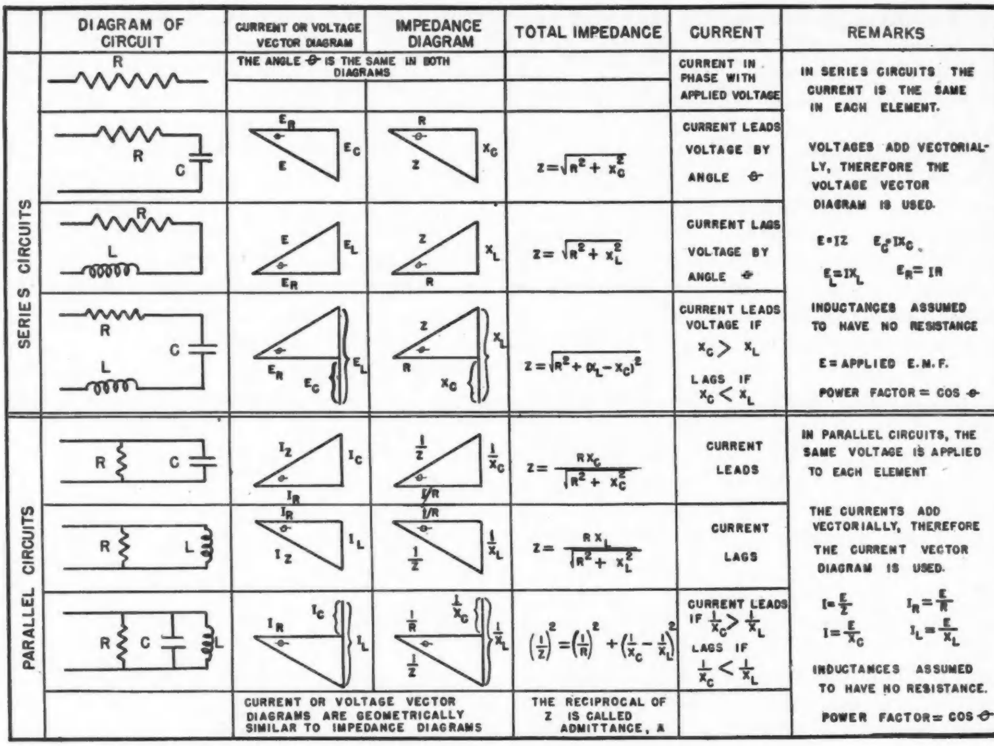

FIG. 1. Properties of simple alternating-current circuits.

reactances are numbers which are easily squared, a troublesome factor is eliminated and a surprising number of students quickly learn to work the problems. Table I gives various values of inductance and capacitance at three common frequencies which result in more usable values of reactance. This table was first suggested and partially calculated by a student whose name, unfortunately, is not available. The instructor will find that a copy of this table in the back of his textbook is of inestimable value in quickly preparing practice work.

Many students enter electrical engineering courses with the idea rather firmly implanted that all alternating-current circuits are to be solved as series circuits. To treat both series and parallel circuits adequately, a knowledge compressor is required, and one such is suggested in Fig. 1. This chart is published in the laboratory manual which students are encouraged to bring to the classroom discussion period. The instructor spends most of his time on the factors that dictate the choice of voltage or current vector diagrams in solutions of certain problems; otherwise the chart is almost self-explanatory. It is unfortunately true that all the problems of alternating currents cannot be included in college physics; for instance, problems involving circulating currents in parallel capacitance-inductance circuits probably should not be discussed in sophomore physics. Problem work is provided by a form given in Fig. 2. A great many answers are to be obtained, but with circuit components chosen from those listed in Table I, the arithmetic, even if a slide rule is not used, need not be burdensome. This form sheet, the authors feel, provides one of the most satisfactory assignments in the whole year's work in physics. Numerous spot problems on examinations indicate that a better understanding of theory can be expected than before such aids were introduced.

The laboratory experience with alternating

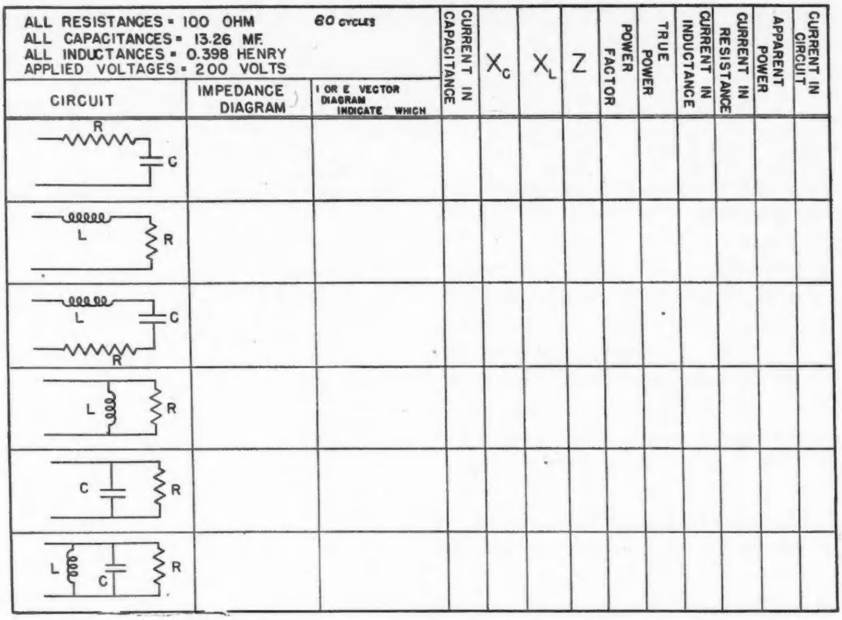

FIG. 2. Example of problem sheet for alternating-current circuits.

currents is confined to one experiment. The magnitudes of the inductors, resistors and capacitors supplied, are either printed on the elements or can be calculated from voltmeter-ammeter readings. These circuit elements are then used in a rather conventional manner. Inadvertently it was found that an iron-frame solenoid used in remote electric control of machinery made an excellent variable inductance. Among the surplus war property shipments were found a number of coils manufactured by National Acme Company (No. 16K100G-S-P4). The unit is actually a small rectangular iron-core solenoid with a movable core designed for 440 v, 60 c/sec, and having a d.c. resistance of about 38 ohms. By clamping the armature, the inductance can be varied over a rather wide range. When the device is used on 110 v with a small air gap, the iron does not saturate; when it is connected in parallel with a 6–8 μf capacitor, the current circulating between the inductor and capacitor is several times the line current.

I would entreat these wise and prudent fathers to consider diligently the difference between opinionative and demonstrative doctrines, to the end that they may assure themselves that it is not in the power of professors of demonstrative sciences to change their opinions at pleasure.—GALILEO.

Water Prisms and a Ray-Tracing Device for Demonstrations in Optics

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Water Prisms

BECAUSE they can be made as large as desired, water prisms are useful for demonstrations in optics. Three examples of their application are described herein.

(*a*) A mirror M (Fig. 1) is mounted on a horizontal axis at O, perpendicular to the plane of the figure. The water between the mirror and the free surface constitutes a prism of effective refractive angle 2θ. When sunlight is allowed to fall on the prism a continuous solar spectrum is formed on the wall or ceiling of the room (Fig. 2). By adjusting θ to suit the time of day the spectrum can be made to appear in a convenient place. If the mirror is large, say 10×50 cm, the long side being parallel to the axis, the spectrum is 50 cm wide. Obviously, a glass prism that would give so wide a spectrum would be both heavy and costly. The mirror should be protected by an antitarnish coating.

(*b*) A shallow water prism is made with two faces of plate glass, 10×40 cm (Fig. 3). It is mounted on a rotating table on the lecture desk, and a burning candle or other, similar light source is placed at B near the blackboard. A student at E sees the image of the candle at B' and observes that, as the table is rotated, B' moves. To aid in locating the position of B' and in determining the angle of minimum deviation, a 2-m scale MM may be hung on the blackboard. As the table is rotated, students in all parts of the room will at some time be able to see the motion of the image B' and thus come to appreciate the significance of the angle of minimum deviation.

(*c*) To demonstrate total internal reflection one may use a large rectangular tank of water with glass sides (Fig. 4), say, 10 cm high and 10 cm wide. An object at C can be seen by looking upward from a point near C'. The angles θ_1 and θ_2 are approximately 62° and 49°, respectively. To show the inversion of the image, a few lines containing, say, 100 letters may be written on a ground-glass plate or typed on a cellophane sheet placed at C and illuminated by daylight from a window. The totally reflected image will then be clearly seen. The apparatus may be made into a permanent exhibit in a physics museum.

Ray-Tracing Device

A means for quickly and accurately drawing on the blackboard a set of incident and reflected or refracted rays is useful in teaching geometrical optics. In the demonstration of the geometric theory of rainbow formation, for instance, several dozen rays properly drawn are needed to give the required result and in particular to bring out the significance of the angle of minimum deviation.[1]

A geometrically simple ray-tracing device for such blackboard use is shown in Fig. 5. It consists of two parallelograms $BCDE$ and $BFGH$ attached to a straight bar NN. The sides of the parallelograms are made of strips of hardwood some 20 mm wide and 4 to 6 mm thick. The lengths of the pieces are such that $BFGH$ is equilateral and $BC/BF=n_1/n_2$. In particular, if

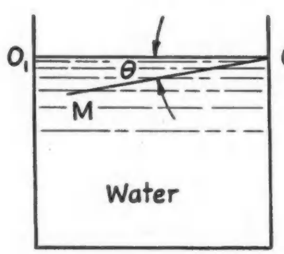


FIG. 1. Improvised water prism.

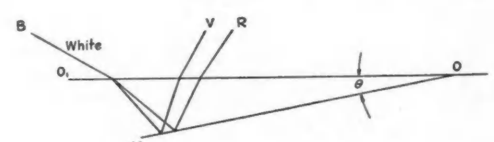


FIG. 2. Spectrum formed by improvised water prism.

[1] See, for example, W. J. Humphreys, *Physics of the air* (McGraw-Hill, ed. 2, 1929, or ed. 3, 1940), Fig. 174; or R. Glazebrook, *Dictionary of applied physics* (Macmillan, 1923), vol. III, article on "Meteorological optics," Fig. 4.

refraction at the interface between air and water is being considered, $BC/BF=\frac{3}{4}$. Convenient values are: $BC=30$ cm, $BF=40$ cm, $NN=110$ cm. When these conditions are met, the rays represented by AB and BF are always conjugate in the sense that if one is the incident ray, the other is the refracted ray. For, by construction, $\sin\theta_1/\sin\theta_2=(h/BC)/(h/BF)=BF/BC=n_2/n_1$. Similarly the rays represented by BF and BH are always conjugate in the sense that if one is the incident ray, the other is the reflected ray. For in the right triangles BFK and BHK, $BF=BH$, and hence $\theta_2=\theta_3$.

The pieces forming the parallelograms are joined by hinges, of which B and E are fixed in NN, while the others are free. Hinges F and G are guided by narrow slots cut in CD and NN. The other slots shown in Fig. 5 are guides for the chalk used in drawing.

To use the apparatus, B is put at the point of incidence and NN is made perpendicular to the reflecting or refracting surface. Then D is pushed forward or backward to obtain the desired value of θ_1 or θ_2. Short, sharp pins at B and E may be of assistance in fixing the direction of NN.

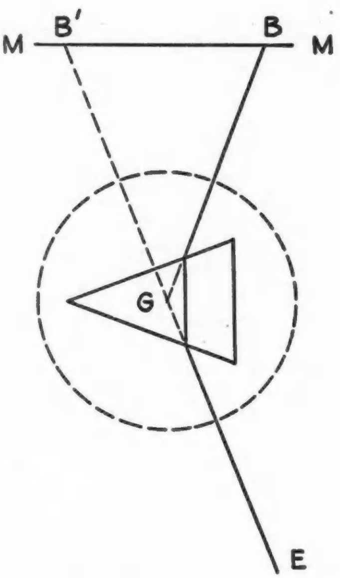


FIG. 3. Water prism used to demonstrate angle of minimum deviation.

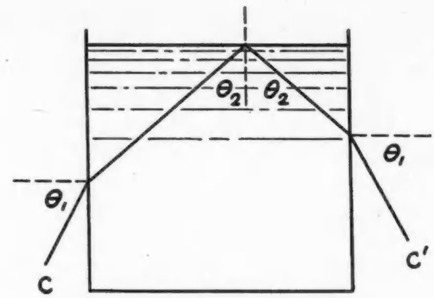


FIG. 4. Total internal reflection.

The apparatus was originally designed to aid in discussing the formation of rainbows. A large circle, say 20 cm in radius, represents a spherical raindrop. Some ten parallel rays may be shown incident on, say, the upper left-hand quadrant of the circle. Then the paths of these rays after refraction by the drop are easily drawn, and the point of incidence B_1 and angle of incidence θ_1, corresponding to the ray having minimum de-

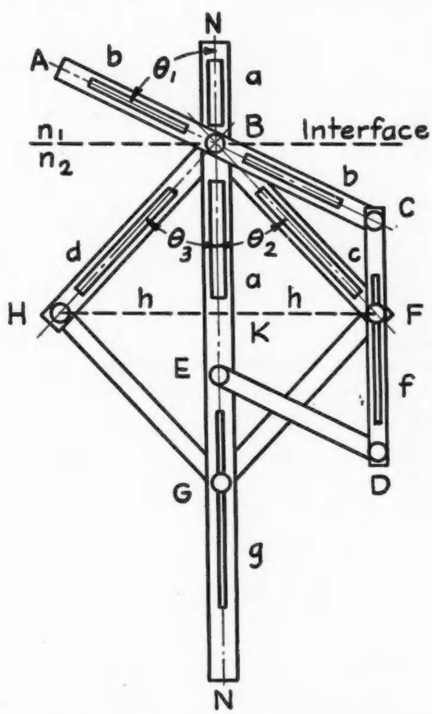


FIG. 5. Blackboard ray-tracing device.

viation in the formation of the primary rainbow by one internal reflection, can be readily obtained with sufficient accuracy for purposes of demonstration. By drawing a group of parallel rays incident on the lower left-hand quadrant of another large raindrop the formation of the secondary rainbow with two internal reflections can similarly be obtained, together with the point of incidence B_2 and angle of incidence θ_2 for the ray of minimum deviation. On tracing rays incident roughly at corresponding points B_1 and B_2 and angles θ_1 and θ_2 in separate figures, the relations of the angles entering into the geometric theory of the formation of the primary and secondary rainbows are clearly shown. The formation of the tertiary and quaternary bows can be similarly explained.

* * *

The apparatus described herein was constructed in the physics shop of the Provincial Kweilin Middle School in 1939 when, owing to war conditions, facilities were very limited. Mr. Fung Chungtai assisted in the design of the ray-tracing apparatus.

The Search for Unity

If we are to have a durable peace . . ., if out of the wreckage of the present a new kind of cooperative life is to be built on a global scale, the part of that science and advancing knowledge will play must not be overlooked. For although wars and economic rivalries may for longer or shorter periods isolate nations and split them up into separate units, the process is never complete because the intellectual life of the world, as far as science and learning are concerned, is definitely internationalized, and whether we wish it or not an indelible pattern of unity has been woven into the society of mankind.

There is not an area of activity in which this cannot be illustrated. An American soldier wounded on a battlefield in the Far East owes his life to the Japanese scientist, Kitasato, who isolated the bacillus of tetanus. A Russian soldier saved by a blood transfusion is indebted to Landsteiner, an Austrian. A German soldier is shielded from tyhpoid fever with the help of a Russian, Metchnikoff. A Dutch marine in the East Indies is protected from malaria because of the experiments of an Italian, Grassi; while a British aviator in North Africa escapes death from surgical infection because a Frenchman, Pasteur, and a German, Koch, elaborated a new technique.

In peace as in war we are all of us the beneficiaries of contributions to knowledge made by every nation in the world. Our children are guarded from diphtheria by what a Japanese and a German did; they are protected from smallpox by an Englishman's work; they are saved from rabies because of a Frenchman; they are cured of pellagra through the researches of an Austrian. From birth to death they are surrounded by an invisible host—the spirits of men who never thought in terms of flags or boundary lines and who never served a lesser loyalty than the welfare of mankind. The best that every individual or group has produced anywhere in the world has always been available to serve the race of men, regardless of nation or color.

What is true of the medical sciences is true of the other sciences. Whether it is mathematics or chemistry, whether it is bridges or automobiles or a new device for making cotton cloth or a cyclotron for studying atomic structure, ideas cannot be hedged in behind geographical barriers. Thought cannot be nationalized. The fundamental unity of civilization is the unity of its intellectual life.

There is a real sense, therefore, in which the things that divide us are trivial as compared with the things that unite us. The foundations of a cooperative world have already been laid. It is not as if we were starting from the beginning. For at least 300 years the process has been at work, until today the cornerstones of society are the common interests that relate to the welfare of all men everywhere.—RAYMOND B. FOSDICK.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

35. Frontispiece to the 1550 Edition of Tartaglia's *La Nova Scientia*

E. C. WATSON
California Institute of Technology, Pasadena 4, California

NICOLO TARTAGLIA (1506–1559) was the first to point out clearly and unambiguously the fact that no part of the path of a projectile is perfectly straight except when the projectile is fired either directly up from or directly down towards the center of the earth.

That he came close to an understanding of the principle of composition of motions is indicated by the following quotation:[1]

> The waigt of the pellet draweth the pellet out of his waie and passage perpendicularly toward the ground when it is shot out of a peece lying levell, and also when it is shot out of a peece elevated or imbased, except it be shot right up towards Heaven, or right downe towardes the ground or center of the worlde.

The frontispiece to the edition of TARTAGLIA'S *La Nova Scientia* published by BASCARINI in Venice in 1550 depicts essentially correct trajectories for two cannon balls fired from the short mortars of the period. As pointed out by HENRY CREW,[2] this represents a considerable advance over the views of the Aristotelians advanced by TARTAGLIA in the first edition (Venice, 1537) of *La Nova Scientia*.

This quaint and charming allegorical woodcut also depicts PHILOSOPHY enthroned at the highest level and alone in the upper circle to which entrance is to be had by way of ARISTOTLE and PLATO. In the lower circle TARTAGLIA himself appears surrounded by the Muses and four figures representing the Pythagorean quadrivium (arithmetic, music, geometry, and astronomy). The implication obviously is that the study of philosophy (science) begins with EUCLID and advances through the quadrivium—to which now TARTAGLIA'S own work should be added—to the loftier concepts revealed only by ARISTOTLE and PLATO.

[1] Translation by Cyprian Lucar in his *Three Bookes of Colloquies concerning the arte of shooting in great and small peeces of artillerie* (London, 1588), p. 14.

[2] *The rise of modern physics* (Baltimore, 1935), pp. 77–81. See also H. Margenau and A. Wightman, *Am. J. Physics* 12, 119 (1944).

A moment's insight is sometimes worth a life's experience.—R. W. EMERSON.

NOTES AND DISCUSSION

Use of the Hartmann Formula

A. W. FOSTER AND FELIX A. E. PIRANI
University of Western Ontario, London, Canada

IN the determination of the wavelength of spectrogram lines it is common practice to use the Hartmann formula,

$$\lambda=\lambda_0+c/(d-d_0), \tag{1}$$

where λ_0, c and d_0 are constants, and d is the particular reading on the plate that gives the distance of the line of wavelength λ from some arbitrarily assigned zero. The following simplified method of making the calculations avoids the laborious arithmetic involved in numerical solutions.

Three identified lines are chosen, whose distances d_1, d_2, d_3 from the arbitrary zero, together with their wavelengths λ_1, λ_2, λ_3, represent coordinates corresponding to three points on a dispersion curve. The origin of this curve is effectively moved to one of the three points by making, say, $\lambda_3=0$ and $d_3=0$, and then the other two lines have new coordinates

$$\lambda_1'=\lambda_1-\lambda_3, \qquad d_1'=d_1-d_3,$$
$$\lambda_2'=\lambda_2-\lambda_3, \qquad d_2'=d_2-d_3.$$

The Hartmann constants can now be calculated from the relations

$$\lambda_0'=-\frac{\lambda_1'\lambda_2'(d_1'-d_2')}{\lambda_1'd_2'-\lambda_2'd_1'}, \quad d_0'=-\frac{d_1'd_2'(\lambda_1'-\lambda_2')}{d_1'\lambda_2'-d_2'\lambda_1'}, \quad c'=\lambda_0'd_0'.$$

These relations were obtained by simultaneous solution of three equations of form (1), corresponding to the three chosen lines.

To find the wavelength λ of some other spectrum line whose distance d from the arbitrary zero has been measured, we get $d'=d-d_3$ and substitute in the relation

$$\lambda'=\lambda_0'+c'/(d'-d_0').$$

The required wavelength is then given by $\lambda=\lambda'+\lambda_3$.

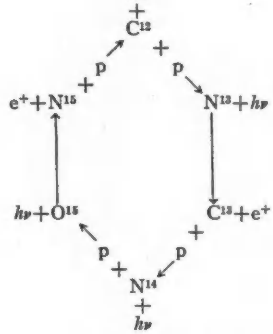
A Mnemonic for Bethe's Solar-Energy Reactions

C. A. RANDALL
University of Michigan, Ann Arbor, Michigan

THE cyclic nuclear process which Bethe[1] has proposed as the source of the energy of the sun is well known. Essentially, it consists of an ingeniously contrived series of reactions whereby four protons are combined in sequence to form helium, each proton having the thermal energy appropriate to the temperature of the interior of the sun—20×10^{6}°K. The original carbon, which enters as a catalyst, is recovered after 5×10^{6} yrs. The series of reactions as usually written is:

$$C^{12}(p,\gamma)N^{13},$$
$$N^{13}\rightarrow C^{13}+e^{+},$$
$$C^{13}(p,\gamma)N^{14},$$
$$N^{14}(p,\gamma)O^{15},$$
$$O^{15}\rightarrow N^{15}+e^{+},$$
$$N^{15}(p,\alpha)C^{12}.$$

This series can be put in more graphic and compact form, and consequently can be remembered more easily, by simulating the benzene ring of the chemists, thus:



The long arrows indicate disintegration of unstable isotopes. This arrangement displays several interesting symmetries that appeal to the student.

[1] H. A. Bethe, *Physical Rev.* **54**, 248 (1938); **55**, 434 (1939).

An Anecdote of Planck

HERBERT M. REESE
University of Missouri, Columbia, Missouri

IN the winter of 1911–12, the writer attended in Berlin the lectures of the late Professor Max Planck on heat radiation. At the beginning the subject was treated only from the classical theory, following rather closely the earlier chapters of Planck's book.

The class of about 50 included a few American and English students. One of these, whose name I have now forgotten, was concurrently reading Planck's book and keeping a little ahead of the lectures, partly to help him in his troubles with the language, partly with the aim of understanding the subject better.

One morning Planck was developing at the blackboard the dynamics of a set of plane waves reflected normally from a completely reflecting plane surface. He represented the incident waves by the usual equation, $y=f(t-x/v)$, and was leading up to the corresponding equation for the reflected train. He knew, of course, that this should be $y=-f(t+x/v)$, and wrote this on the board. But the hour was nearly at an end, and in hurrying to bring the lecture to a suitable close he became a little confused and forgot why the negative sign must be placed before the function for the reflected waves. He hesitated, stammered, apologized, and said he would have to straighten the matter out at the following lecture. He then dismissed the class, two or three minutes before the proper time.

The English-speaking student mentioned above saw clearly where Planck had gone astray, and as the rest of the class left the room he walked up to the lecturer's desk, and the following conversation occurred, in German.

Student: "Professor, I think it is perfectly right to affix the negative sign before the function for the reflected wave."

Planck: "Yes, but why?"

Student: "Well, the only requirement is that the boundary condition be satisfied."

Planck: "You are perfectly right! Except for that, it is a completely arbitrary function. I cannot understand why I suddenly forgot the point."

Next morning Planck again apologized for his failure on the preceding day, and went on to say that one of the students had come up and recalled to him the reason for the negative sign. This incident has remained very vividly in my mind for two reasons. First, it shows that even a master of his subject can sometimes become rattled in a lecture. But still more, it shows the fundamental sincerity and generosity of Planck's character. He was a fine, modest, cultured gentleman, who never showed the arrogance that we sometimes associate with aristocratic Germans.

An Interesting Application of Archimedes' Principle

JOHN M. CHILTON
Agricultural and Mechanical College of Texas, College Station, Texas

An amusing demonstration to illustrate buoyancy effects may be set up with carbonated beverages and immersed objects of slightly higher specific gravity. If the specific gravity ratio is just right the body will sink, collecting bubbles of carbon dioxide as it descends, until the buoyant force exceeds the weight. The object will then rise, releasing some of the bubbles when it surfaces. It will then sink, and the process will continue until the liquid is decarbonated.

The object may be a lemon or orange seed in Seven-up or carbonated water, or, as the author has found more satisfactory, salted peanuts in beer. This combination will usually work admirably if the temperature of the beer is not too low, whereas the seed will require a considerable reduction of the specific gravity of the carbonated drink with alcohol or some other miscible liquid of low density.

The author has demonstrated the effect with peanuts and beer many times and has never seen it fail. However, since all beers and all peanuts are not identical, it is desirable to immerse many peanuts instead of just one, for out of 20 or 30 there will always be several that have the correct specific gravity and these will surface and sink without attention for an hour or so. It is important that the beer be not too far below room temperature, for the specific gravity ratio is rather critical. If patience deteriorates, the density of the beer may always be reduced to the proper value by the addition of a small quantity of alcohol.

The addition of salt will stimulate the release of carbon dioxide and revive the process after it has become sluggish from decarbonation.

RECENT MEETINGS

Southern California Section

The regular fall meeting of the Southern California Section of the American Association of Physics Teachers was held in the Norman Bridge Laboratory of Physics of the California Institute of Technology in Pasadena on Saturday, October 25, 1947. There were 156 persons at the meeting, of whom 57 were members of the Section and 99 were guests. Eighty-eight members and guests attended the luncheon given at the Institute between the morning and afternoon sessions.

The following program of 10-minute contributed papers was heard in the morning session.

Easily constructed apparatus for the measurement of the range of alpha particles in air. V. L. BOLLMAN, *Occidental College.*

Effect of atmospheric pressure on the thrust of a rocket. H. S. SEIFERT, *California Institute of Technology.*

Analysis of a recent term's work with a pre-engineering class of 450 students, 75 percent of them veterans. L. E. DODD, *University of California at Los Angeles.*

Philosophical aspects of the reciprocal electric force. F. W. WARBURTON, *University of Redlands.*

Model to demonstrate the refraction of light at a boundary between two media of different indices of refraction. F. R. HIRSH, JR., **Pasadena, California.**

Method of obtaining the average acceleration in the free-fall experiment. D. P. BENDER, *Whittier College.*

Pictorial summary of magnetic knowledge in the 17th century. E. C. WATSON, *California Institute of Technology.*

Education—or merely training (continued): The importance of units in physical quantities. G. FORSTER, *Pasadena City College.*
Cross-hairs. D. B. PHELEY, *Los Angeles City College.*
Electrical structure of thunderstorms. R. E. HOLZER, *University of California at Los Angeles.*
The successful teacher of physics—what makes him tick. W. P. BOYNTON, *Oregon State College.*

Between the morning and afternoon sessions a large proportion of those present enjoyed browsing through the historical scientific material on display in Professor E. C. Watson's office.

The afternoon session was unusually rich in having two invited papers:

The anniversary of the discovery of the electron. R. A. MILLIKAN, *California Institute of Technology.*
The story of radar. L. A. DUBRIDGE, *California Institute of Technology.*

Doctor Millikan's talk was given as part of the recognition being given this year to the 50th anniversary of Sir J. J. Thomson's work on the electron. While not subtracting in any way from the credit due Thomson, Doctor Millikan, by reading from Franklin's *Collected Letters*, brought out the interesting point that Franklin, 200 years ago, had essentially demonstrated the existence of a unit charge of electricity.

Doctor DuBridge in his talk developed the basic physical considerations that govern the design of radar systems.

At the business meeting following the afternoon session the Section heard Mr. Earle C. Enholm, of Long Beach City College, report on the work to date of the Teaching Load Committee. This committee is investigating the facts behind the widely held opinion that high school and junior college physics teachers in this area are so heavily loaded with both teaching and nonteaching duties that they are not able to do as effective teaching as they would like to do. The circulation of a questionary was announced for the near future; a more detailed report based on the returns from the questionary will be presented to the Section at the spring meeting.

Dr. David L. Soltau of the University of Redlands was elected to represent the Section on the Executive Committee of the Association.

FOSTER STRONG,
Secretary-Treasurer

Western Pennsylvania Section

The regular fall meeting of the Western Pennsylvania Section of the American Association of Physics Teachers was held on December 6, 1947 at Carnegie Institute of Technology, Pittsburgh. Sixty-four members and guests were in attendance. The meeting opened with an address of welcome by W. N. Jones, Director of the College of Engineering. Charles Williamson, President of the Section, presided. The following papers were presented:

An adiabatic calorimeter. J. S. ARTHUR, *Washington and Jefferson College.*
Accommodation mechanism of the human eye. O. BLACKWOOD, *University of Pittsburgh.*
Elementary thermodynamics for Physics I. R. C. HITCHCOCK, *Indiana State Teachers College (Pa.).*
General Electric science fellowships. W. L. WIEGMAN, *South Vocational High School (Pittsburgh).*
The coming Carnegie Institute synchro-cyclotron. E. C. CREUTZ, *Carnegie Institute of Technology.*

Luncheon was served in the Faculty Dining Room. At the business meeting, A. J. Kozora, of Duquesne University, was elected Vice President of the Section. The meeting ended with trips through the physical laboratories of Carnegie Institute and the presentation of teaching demonstrations.

HARRY HILL,
Secretary.

New England Section, American Physical Society

The 29th meeting of the New England Section of the American Physical Society was held at Wesleyan University, Middletown, Connecticut, on November 1, 1947. One hundred and two members of the Section registered. The program included the following invited papers, the last four of which formed a symposium on physics of the solid state.

The demonstration lecture—art or craft? V. E. EATON, *Wesleyan University.*
Recent experiments at high pressures. P. W. BRIDGMAN, *Harvard University.*
The dependence of dry friction on the bulk properties of metals. J. T. BURWELL, JR., *Massachusetts Institute of Technology.*
Use of the print-out effect in studying the motion of electrons in silver chloride crystals. J. R. HAYNES, *Bell Telephone Laboratories.*
Properties of quartz crystals. K. D. VAN DYKE, *Wesleyan University.*

Abstracts of the ten-minute contributed papers will appear in the *Physical Review.*

At the business meeting, the following officers were elected for 1948: *Chairman*, K. T. Bainbridge, *Harvard University; Vice Chairman*, Mildred Allen, *Mount Holyoke College; Secretary-Treasurer*, G. F. Hull, Jr., *Dartmouth College; Program Committee*, W. P. Allis, *Massachusetts Institute of Technology*, C. T. Lane, *Yale University.*

GORDON F. HULL, JR.,
Secretary-Treasurer

DIGEST OF PERIODICAL LITERATURE

Outside Opinion on Physics for Premedical Students

A questionary on premedical education was sent in November 1944 to all medical schools and about 300 colleges and universities by Alpha Epsilon Delta, national honorary fraternity for premedical students. Of 94 replies received, 41 were from the medical schools. In some cases more than one reply was received from a single institution; in several cases, the reply represented the composite opinions of a number of faculty members.

The replies to 4 of the 18 questions asked may be summarized as follows.[1]

What do you consider to be the most outstanding defect in premedical education in your school?

The outstanding defects appear to be: inability to speak and write good English, serious deficiency in the humanities, and too much "information without thought" in college teaching. To a lesser degree it is felt that premedical students need not more but better skill in the use of simple mathematics and better training in physics. The latter problem we suspect to be a much larger one than is indicated by the replies. Indeed, of 72 replying, only 7 mentioned physics as the weak spot in their institutions. The principal criticism is that physics is too often taught as an engineering tool subject and so rarely is related to biology and chemistry. It is not that the physics is any different, but that the illustrative examples and problems might be better chosen. Another criticism is that physics teachers do not concern themselves with the special needs of nonengineering students.

Do you feel that there is any marked over-emphasis in any field of formal training in your school?

The overwhelming opinion is that the premedical curriculum is well balanced, without serious over-emphasis, and is well suited to meet present requirements of medical schools. A small minority feel that there is too much science, especially chemistry; but, when these opinions are correlated with the replies to the preceding question, the indication is that more nonscience, not less science, is needed and would be approved.

How can premedical training in physics be improved?

This question was included in the questionary because of complaints from nearly all medical schools and, especially, from physiologists who have found their medical students singularly lacking in understanding of the physical principles involved, not only in physiological apparatus, but in the processes carried on in living systems. This is an important defect; for, without understanding of both the chemical and physical properties and processes in living organisms, the student is working in the dark with rule-of-thumb methods and is in constant danger of making disastrous mistakes in judgment. *Understanding* of these ideas is in exactly the same category as understanding of the principles and applications of genetics, host-parasite relationships, physiological actions of drugs (themselves chemical and physical relationships), and the nature of pathological processes (also chemical and physical processes). One who constructs a bridge or a system of levers makes use of physical laws; just so does Nature in the repair of a bone, or in maintaining water-balance and temperature regulation. Many scientists would go so far as to say that *all* biological processes are nothing more than applications of chemical and physical laws and processes. It would be difficult to prove otherwise on other than abstract philosophical grounds.

Yet it appears that many if not most premedical students get no hint or at least no appreciation of these fundamental relationships in their formal training in physics. The survey of opinion on preparation for medicine conducted by the University of Illinois in 1944 showed that three or four years later, as juniors and seniors in medicine, students realized this deficiency and urged more and better preparation in physics. Medical educators see the lack and urge better preparatory courses. It is a direct and inescapable challenge to the teachers of physics to provide the needed understanding.

The following statements are indicative of the sort of replies received to this question. It is to be regretted that the physicists are not represented in larger numbers in this report. However, we believe that they will take the replies in the spirit in which they were written—in the sincere desire to improve this weak spot in premedical education.

> The average physics instructor has not had training in biology and very little in chemistry. He is generally the most specialized of all the science instructors.
>
> Get better physics teachers. The ranks are full of old and young crabs who feel that the moment a subject becomes interesting, it is no longer scientific; hence, that it must be as abstract and as full of mathematical formulas as possible. Such teachers are unable to explain the simplest phenomenon in terms understandable to the beginner. They give the student the feeling that physics is the domain solely of the physicist with a "no trespassing sign" on the door. Incidentally, the writer once flunked an entire physics department on the explanation of why the frustule of a certain diatom was a brilliant steel blue under medium power of the microscope, but completely colorless under the high power. Perhaps the biologist might even teach the physicist a little physics!
>
> The important consideration is better teaching, not revision of content or change of emphasis.
>
> The experience of the armed forces in teaching poorly trained men the use of vacuum-tube circuits such as those employed in radar should stand as a challenge to departments of physics, which fail at present to impart in eight semester-hours enough of the fundamentals of optics and electricity to enable students even to recognize this material when later confronted with it.
>
> Laboratory work should receive greater emphasis, and it should be coordinated with the lectures. Also, medical students generally find it strikingly difficult to think quantitatively, and physics could be made an ideal subject for developing this ability.
>
> The training in physics can be improved by convincing the premedical student that physics is no less important than chemistry or biology.
>
> Eliminate the morons and imbeciles from physics classes, and then "pour it on." It is not easy to teach physics to students who were passed out of high school mathematics classes in order to get rid of them.

The general criticism coming to me over a period of 15 years is that all the physics instructor does is to work problems. Some one should be able to develop a course in physics in which nonmathematical methods are used in explaining physical processes.

Physics is usually very good as it is.

Physics is of course physics, but some biological applications would give it more life and would help those who are biologically inclined; and, after all, it would be just as good physics.

Reduce the number of hours of required physics and concentrate on the real and fundamental principles. It is my personal opinion that the requirement of a full year of physics for entrance into medicine is a contrivance designed by the physicists themselves to give them someone to teach.

A physics textbook written from a premedical point of view would be of great help.

In summary we wish to point out that it is much easier for an outsider to criticize conditions in any field such as physics than to correct or improve them. Some of the replies were so general in nature as to be nearly meaningless. If those who suggested improvement "by vitalizing the subject" meant relating it more to living things, we would agree; if they meant to vitalize it in the progressive school sense of making it more "interesting," more fun, less work, we would disagree. Any subject will become interesting as one works and acquires knowledge and skill in it; but it should be not superficial and time-consuming play-acting, but serious investigation of the subject.

As we said, it is easier to criticize than to improve. No doubt most of our respondents, if pressed, would pass the responsibility on to the physicist and wash their hands of it. Others would be willing to work actively in compiling suggestions, technics, problem materials, experiments and applications, and in putting such suggestions into workable form for physics teachers. It has been said that physicists should go back and study biology and find out for themselves what to do. This immediately raises the question in the physicist's mind as to what he should study and what applications he should use. We believe that teachers in other fields such as zoology, physiology, biochemistry and pharmacology should and would gladly work with physicists in developing new technics and applications for the premedical student and others concerned with biological problems.

Besides the general course in physics, do you think that premedical students should have a special course in the principles and operation of instruments and devices used in medical research and practice, such as induction coils, electrocardiograph, vacuum-tube generators and amplifiers, radioactivity, optical instruments, and so forth? Discuss.

The opinion on this question is nearly two and a half to one against such a course of training—the figures being 17 for and 41 against. Since a number of replies indicated that the principles are or certainly should be included in any general course in physics, and that *principles* rather than applications are all that are needed in premedical courses, we have included these replies in the "against" column even though they did not indicate outright opposition. It is interesting and significant that more teachers in premedical colleges favored the course than did the medical group; this is significant in that it indicates the desire of the premedical teacher to furnish any and all training that appears to be necessary for the student. Often these teachers ask the question "what do the medical schools think of this idea or do they want it?," or answer a query with "that is for the medical schools to say." The medical teachers should deeply appreciate this desire to do whatever is felt necessary to equip premedical students properly. It is sometimes felt that educators in the colleges are more concerned with the basic quality of the curriculum and the student as a man than some medical educators are.

To summarize this discussion, most medical and premedical educators do not feel that a special course in physics dealing with instruments, their operation and application, is desirable. The reason most often given is the sound one—that the principles are or should be included in the elementary course and the actual *uses* in medicine should be left for the medical school to teach in connection with clinical experience. For the benefit of the premedical teachers of physics who feel that the course is desirable, it is urged by many of our respondents that their efforts might be better spent, and would be of more lasting value, if they did a better job of teaching the fundamental laws and principles of physics with enthusiasm and consideration for the interests of the students. Not all students before them are going to be either physicists or engineers, or even physicians. Yet all educated persons should have some understanding of the physical nature of the universe.—H. E. SETTERFIELD, *The Scalpel of Alpha Epsilon Delta* **17**, 97–140 (1947).

[1] In the complete report, the replies to most of the 18 questions are discussed more fully than the present digest indicates. A copy of the complete report may be obtained from Dr. Maurice L. Moore, 3853 Lakewood, Detroit 15, Mich.—D. R

A Simple 1000-c/sec Oscillator

A 6SN7GT dual-triode tube is used as a cathode-coupled oscillator that can be operated from a 6-v battery. The frequency of oscillation is determined by an *LC* circuit, the constants of which may be adjusted to give approximately 1000 c/sec with good wave form. The frequency stability is excellent. The oscillator is useful for measurements of conductance of solutions. Since the background noise of the common microphone hummer is absent, the null point in bridge measurements is more easily determined.—A. P. MARION, *J. Chem. Ed.* **24**, 394 (1947).

There is nothing more likely to betray a man into absurdity than condescension—when he seems to suppose his understanding too powerful for his company.—SAMUEL JOHNSON.

NECROLOGY

Shuichi Kusaka, 1915–1947

The recent untimely death of Shuichi Kusaka, a well-known theoretical physicist, has been a great loss to all of physics, and an especially great loss to those who knew him personally. At the time of his death, he was an Assistant Professor of Physics at Princeton University, and was widely recognized for his research in the field of cosmic rays.

While swimming at Beach Haven, New Jersey, on August 31, 1947, with a group of friends, he became separated from the group, and although his body was soon discovered, attempts to revive him were unsuccessful. He is survived by his father and mother and one sister, who now live in Japan, and by another sister living in British Columbia.

Doctor Kusaka was born in Osaka, Japan, in 1915. At the age of 5, he came to British Columbia with his family. Although his mother and father returned to Japan, he remained with his sister. He later attended the University of British Columbia, where he received his A. B. degree in 1937, with first honors in mathematics and physics. In 1938, he received an M. S. in physics from the Massachusetts Institute of Technology. He then attended the University of California, studying with Professor J. R. Oppenheimer. He received his Ph.D. in 1942, and then held a special traveling fellowship at the Institute for Advanced Study during the following year, at which time he worked with Professor W. Pauli.

After spending the next two years as an instructor at Smith College, he volunteered for the army and became an American citizen. Upon release from the army, he came to Princeton and worked with Professor J. A. Wheeler, continuing his research in cosmic rays.

While still a graduate student at the University of California, Doctor Kusaka, working with Professor Oppenheimer and Doctor Christie, carried out an important theoretical investigation concerning the production of bursts of high-energy gamma-rays by the cosmic-ray mesons. As a result of their work, it was possible to conclude from the observed rate of production of bursts in cosmic rays that the meson could have a spin of either zero or one-half, but not larger.

Later, Doctor Kusaka, working with Professor Pauli, who was then at the Institute, and Doctor Weinberg, then at the University of California, investigated the wave equations which might represent particles of spin higher than unity. This is a problem that has engaged the attention of many other theoretical physicists, and it must still be regarded as one that requires further study, particularly in view of the fact that so many different kinds of mesons seem to be produced by the cosmic rays.

At the time of his death, Doctor Kusaka was working with Professor Wheeler on the theory of the production of stars by gamma-rays coming from cosmic rays, and he had just started some theoretical work with Professor Oppenheimer on the calculation of the line shifts in hydrogen, measured recently by Lamb and Retherford.

During the war, Doctor Kusaka inevitably encountered a considerable amount of anti-Japanese feeling. Those who knew him, however, never doubted his loyalty to the United States, and many of his associates, particularly Professor Oppenheimer, Doctor Frank Aydelotte, then director of the Institute for Advanced Study, and Professor Gladys Anslow, Chairman of the Department of Physics at Smith College, made strong efforts to help him through this difficult period. During this time, all of his friends were very much impressed by his courage and strength of character.

Although his nature was somewhat shy and retiring, those who knew him well found him to be an extremely generous, kind, and good-natured person. He had many friends at Princeton and elsewhere, and at the time of his death he was actively engaged in research into problems that are in the forefront of modern physics.

Doctor Kusaka's death at this time was particularly tragic, because he had successfully overcome the problems with which he was confronted during the war, and was once more continuing a career in which he showed great promise.

David Bohm
Robert R. Bush

New Members of the Association

The following persons have been made *members* or *junior members* (*J*) of the American Association of Physics Teachers since the publication of the preceding list [*Am. J. Physics* **15**, 524 (1947)].

Albert, Earl G., State Teachers College, River Falls, Wis.
Albright, John G., Rhode Island State College, Kingston, R. I.
Allen, George W., 360 High St., West Medford, Mass.
Anderson, Roy Stuart, 9 College St., Hanover, N. H.
Anselmo, Vincent, Salinas Junior College, Salinas, Calif.
Bainter, Monica E., 1214 A Wisconsin St., Stevens Point, Wis.
Baker, Donald Hart, Qrts. 11, M. C. M. & T., Sault Ste. Marie, Mich.
Baker, John H., 1450 Boston St., SE, Grand Rapids, Mich.
Barling, W. Henry (*J*), 1816 Clover Lane, Ft. Worth, Tex.
Bates, John F., 2440 Lakeview Ave., Chicago 14, Ill.
Benson, Bruce B., Amherst College, Amherst, Mass.
Brickley, Dick, Jr. (*J*), 1128 Fairmont Ave., Ft. Worth, Tex.
Bridgforth, Edwin B., Box 145, State College, Miss.
Bryan, J. Ned, Jr., 416 Grant Ave., Morgantown, W. Va.
Buchanan, Alfred K., 131 W. Main St., Plantsville, Conn.
Cahnman, Gisella L., 212 E. 13 St., New York 3, N. Y.
Camp, Paul Rice, 110 Mt. Vernon St., Middletown, Conn.
Chandler, Frank S. (*J*), Box 717, Wilson Center, Norman, Okla.
Clark, Frank M., 20 Tyler, Apt. 404, Highland Park 3, Mich.
Clark, Fred J., Stockton Junior College, Stockton 37, Calif.
Clark, W. P., 1414 Frederic St., Eau Claire, Wis.
Cohen, Ernest, University of Buffalo, Buffalo, N. Y.
Cole, Garnold L., 78 Market St., Potsdam, N. Y.
Cook, David Livingston, John Brown University, Siloam Springs, Ark.
Cope, David F., A & M College of New Mexico, State College, N. M.
Crews, Robert Wayne (*J*), Oregon State College, Corvallis, Ore.
Crum, J. U., Western Carolina Teachers College, Cullowhee, N. C.
Cummings, Jerry W., Aeronautical University, Chicago, Ill.
Darnell, Vaughn K. (*J*), 4005 Lovell, Ft. Worth, Tex.
David, Abraham, Haifa Technical High School, P.O.B. 910, Haifa, Palestine.
Davis, John F. (*J*), 1103 W. Market St., Crawfordsville, Ind.
DeCotiis, John C., 9 Reed St., Jersey City 4, N. J.
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